D1.2 Workshops report

Deliverable ID:	**D1.2**
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:	**27 June 2024**
Edition:	**01.00**
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).

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Authoring & approval

Author(s) of the document

Organisation name	Date
ENAC	02/04/2024
TUD	02/04/2024
DBL	25/06/2024
ADP	02/04/2024

Reviewed by

Organisation name	Date
TUD	26/06/2024
ADP	26/06/2024
Deep Blue	25/06/2024
Eurocontrol	26/06/2024
ENAC	26/06/2024

Approved for submission to the SESAR 3 JU by[1]

Organisation name	Date
Deep Blue	25/06/2024
TUD	26/06/2024
ADP	28/06/2024
Eurocontrol	28/06/2024
ENAC	28/06/2024

Rejected by[2]

Organisation name	Date

[1] Representatives of all the beneficiaries involved in the project

[2] Representatives of the beneficiaries involved in the project

Document history

Edition	Date	Status	Company Author	Justification
00.01	02/04/2024	Initial version	Garcia / ENAC	The table of content and the overall setup
00.02	12/06/2024	Intermediate version	Garcia / ENAC	Draft of the deliverable is written and provided for internal review
01.00	27/06/2024	Final version	Garcia/ ENAC	The final version with all comments of the project participants addressed

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.

Table of contents

EUROPEAN PARTNERSHIP

Co-funded by the European Union

List of figures

List of tables

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.

In this report, we describe the results of our initial research activities with stakeholders to identify and narrow the first set of expectations of the project.

Background information on Airport ground Operations sets the operational context and identifies relevant stakeholders and procedures that are involved in such operations that will be impacted by the project's concept of operations and use cases. We also describe motivations and challenges to move toward full automation gathered during interviews and workshops from three major airports, Paris-Charles de Gaulle (CDG), Amsterdam Schiphol (AMS) and Frankfurt Airport (FRA). The motivations include increased predictability of the operations or improved environmental performances. The main barriers are technical with the need of centralised data with sufficient temporal and spatial precision to be usable by the algorithms as well as related to human performances and liability.

During the workshops, we identified and refined several use cases that are relevant to pursue research on the ASTAIR concept of operation, Path planning algorithms (WP2) and Human Automation Teaming (WP3). The use cases cover several operational situations in which we propose to reach several levels of automation from assistance to user to high level of automation but also collaboration between humans and AI.

Finally, we highlight specific challenges to achievable levels of automation that will be explored in the remainder of the project focusing on Human Automation Teaming, Path Planning algorithms and Liability.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

1 Introduction

As airport traffic continues to grow, the limited cognitive capabilities of human controllers and the increasing number of vehicles to be controlled result in a high workload for ground controllers and airport operators, especially at major hub airports. Current airport taxi operation procedures have been tailored to optimise operational performance while maintaining workload at a level that does not compromise safety. Designing automation and human-AI collaboration environment capable of performing complex tasks for managing surface engine-off and conventional taxiing movements is key to improving capacity, predictability, and environmental impact while maintaining safety on the ground.

The ASTAIR project aims to design seamless collaboration between humans and Artificial Intelligence (AI) to enable autonomous management of engine-off and conventional taxiing operations across all airport surfaces. Increasing the level of automation overseeing all ground movements will help improve the predictability of airport turnaround operations and manage the additional complexity introduced by engine-off taxiing techniques. ASTAIR's original approach to automation is to consider an integrated airport system instead of many separate subsystems/tools, analyse the level of autonomy an AI system could apply to ground movements tasks, and ensure that the automation is controllable by humans at different levels (i.e., ranging from full human control towards an AI issuing clearances to vehicles).

1.1 Purpose and scope of this document

This document provides background information on the research conducted by the ASTAIR project.

In ASTAIR, we decided to focus on large airports implementing A-CDM since these are more likely to be benefiting from more automation on ground with engine off taxiing techniques and already have dedicated data sharing infrastructure that seems mandatory to implement the ASTAIR envisioned Conception of Operation.

For such a context, we focused on identifying the current operational working procedures (apron management and ground control) and some operational deployment constraint such as data sources. We conducted several workshops with stakeholders to ensure that important requirements are correctly considered all along the concept design phase.

This document presents an overview of ground operations in targeted airports including their operations as well as the involved actors and systems. Based on results from several workshops with stakeholders, the document identifies eight baseline Use Cases and relevant tasks that could be automated. These initial activities will produce initial scenarios for the design of new algorithms and interaction for the remainder of the project.

1.2 Background

In order to identify current practices, baseline scenarios and tasks that could be automated, we carried out several activities:

- The analysis of the state of the art reported in D.1.1 on interaction between human actors and automated systems for the management of ground operations in potentially highly automated airports.
- The analysis of current airport ground operations procedures and the conduction of interviews, observations with air traffic controllers, apron managers, ground handlers or airport operators.
- The conduction of several workshops with stakeholders to identify opportunities for automation; use cases; justifications for the use cases and future needs of an automated airport

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.

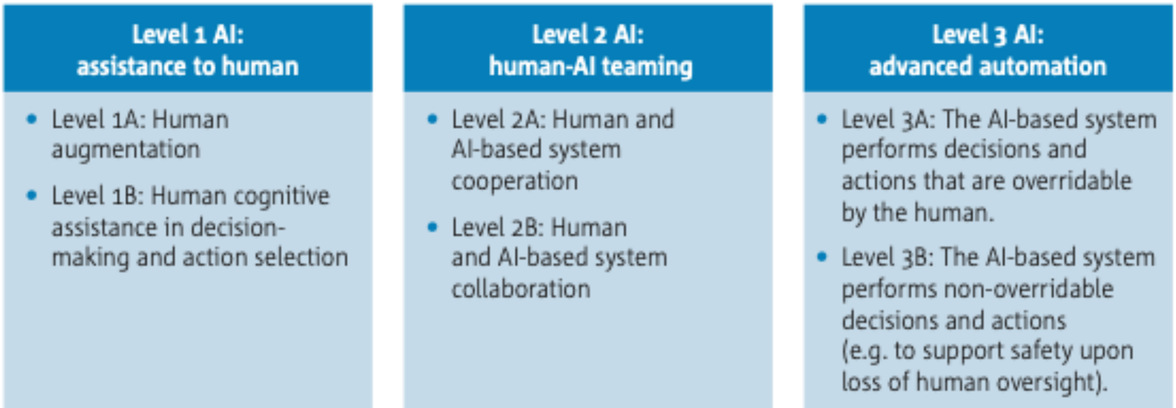

Figure 1: EASA levels of automation defined in [2].

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.

1.4 Structure of the document

Section 2 first introduces airport operations in major airports using A-CDM with the involved roles and their tasks. It describes the results from our work with stakeholders to identify Paris-Charles de Gaulle, Amsterdam Schiphol and Frankfurt Airport motivations to automate ground operations, shared considerations and specificities that are relevant to the ASTAIR envisioned concept.

Section 3 describes the use cases that were elaborated during the stakeholder workshops and refined with the consortium partners including envisioned levels of automation.

Section 4 discusses the proposed levels of automations and the associated hypothesis and challenges regarding Human Performances, Algorithms Performances and Liability based on the results of the workshops.

Section 5 concludes the deliverable and presents how the results will be used within the ASTAIR project.

Co-funded by the European Union

2 Envisioned airports Environnement

The face of airports around the world today, is very much different than that we knew twenty years ago. Airports are operated by various entities including government authorities, private companies, consortiums and public corporations.

Above all, airports differ from each other, and aside to the various data and statistics published from time to time, we understand that airports are complex. The various requirements related to airports can be broadly categorized as either economic or safety-related, in both scenarios under multi-disciplined authorities. The various approaches adopted worldwide are generally based on ICAO Annex 14 – Volume 1: Aerodrome Design and Operations [8].

The multifaceted challenges, along with environmental sustainability issues that rank highly on the industry's list of priorities, reiterate the volatility which aviation stakeholders are exposed to. Amongst others this include the reiteration by EASA's commitment to the Global Market Based Measures on Emissions. Airports are part of the equation and in order to ensure the sustainability of their operations, the international standards and recommended practices need to be developed within a contemporary mind-set which takes into account the issues faced by airport operators today, conscious of increasing traffic and further safety as well environmental awareness.

ICAO Annex 14 requires contracting states to set up a regime of aerodrome certification for their international that was intended to ensure that facilities, equipment and operational procedures. It is understood that one can find registered and other aerodromes too, but in particular for this project, airport operations are considered for certified airports only. Indeed, this project is in line with the process of EASA which responsibilities in the field were extended to aerodromes.

Airports are where the nation's aviation safety system connects with other modes of transportation and where quite often, national responsibility for managing and regulating air traffic operations intersects.

2.1 Airports considered within the ASTAIR project

Within the ASTAIR project, we are targeting major airports with high traffic levels that have a A-CDM operation center and/or are using A-SMGCS to support ATCOs performing their tasks.

The ASTAIR project focused on large airports implementing A-CDM. Such airports are more likely to benefit from more automation on ground with engine-off taxiing techniques due to their longer taxiing time. Also, they have dedicated data sharing infrastructure that seems mandatory to implement the ASTAIR envisioned Conception of Operation, see 2.3.

In addition, ASTAIR needs A-SMGCS as an enabler for the solution. Indeed, ASTAIR needs data from the surveillance service and will propose enhancements for autonomous guidance service for aircraft and tugs on maneuvering areas, see 2.2.4.

Since the foremost enabler to ASTAIR concept is aircraft and tugs able to follow precisely enough speed targets on the taxiways, target airports will preferably use automated taxi thanks to towing or aircraft having autonomous taxi feature[3].

Put together, ASTAIR concept targets large airports with high congestion levels or long average taxi times, implementing A-CDM and A-SMGCS. During the workshops, discussions were held with Paris-Charles de Gaulle, Amsterdam Schiphol and Frankfurt airports.

2.2 ATC operations at a glance

2.2.1 Control Tower operations at a glance

In Figure 2 the main phases of the final approach and tower operations are graphically represented [5]. The aircraft (A/C) is delivered from the final approach/departure unit to the Tower (TWR) controller (responsible for arrivals and departures), and then to the Ground (GND) controller (responsible for the ground traffic). The area of responsibility of the aerodrome controllers covers the aerodrome space. The division of responsibilities between the tower and the approach units cannot be strictly defined and depends on local conditions [7] .

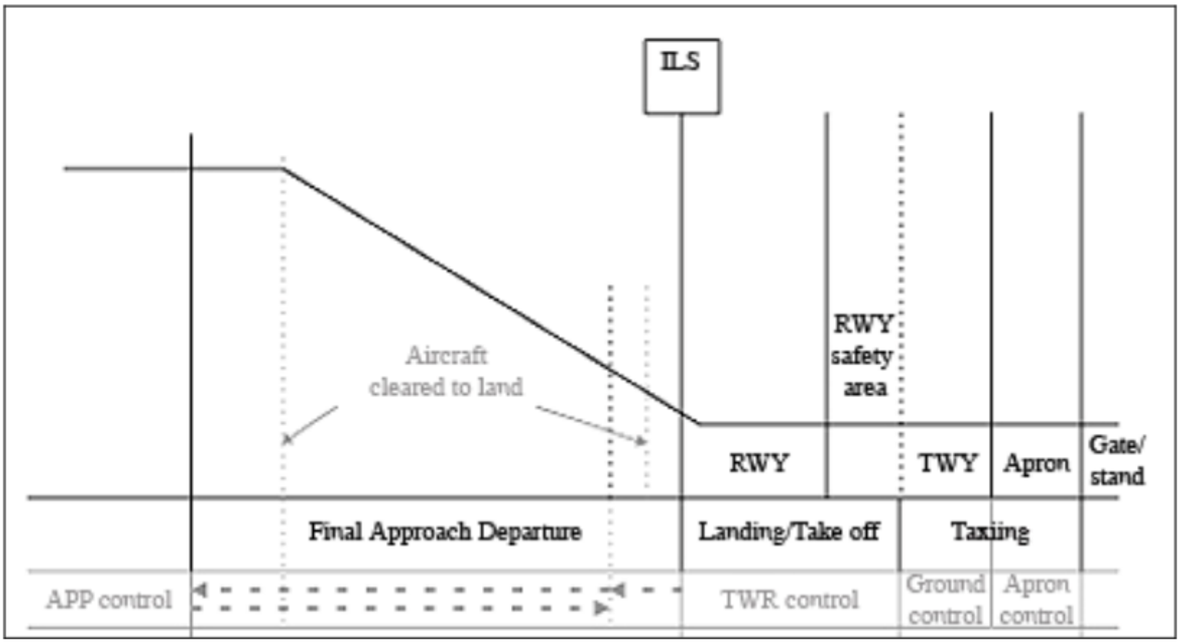

Figure 2: Control tower operations

As defined in [5] *«the aerodrome controllers shall issue information and clearances to aircraft under their control to achieve a safe, orderly and expeditious flow of the air traffic on and in the vicinity of an aerodrome with the object of preventing collision(s) between:*

[3]https://www.airbus.com/en/newsroom/press-releases/2020-06-airbus-concludes-attol-with-fully-autonomous-flight-tests

Co-funded by the European Union

a) *aircraft flying within the designated area of responsibility of the control tower, including the aerodrome traffic circuits;*
b) *aircraft operating on the manoeuvring area;*
c) *aircraft landing and taking off;*
d) *aircraft and vehicles operating on the manoeuvring area;*
e) *aircraft on the manoeuvring area and obstructions on that area».*

The manoeuvring area is defined in [5] as: «that part of an aerodrome to be used for take-off, landing and taxiing of aircraft, excluding aprons». Thus, the manoeuvring area is different from the so-called movement area, which includes also the aprons. This distinction is not trivial because it circumscribes the responsibilities of the controllers. For instance, only the manoeuvring area is dependent on the controllers' monitoring and guidance. According to Bergé [1], the surveillance service should cover aircraft in the apron area, since the controllers need to know the aircraft position with regards to the future conflict on the manoeuvring area; but there is no responsibility from the controllers' side for what is taking place on the apron. This fact is further stressed in [6]: *«Aerodrome controllers shall maintain a continuous watch on all flight operations on and in the vicinity of an aerodrome as well as vehicles and personnel on the manoeuvring area».* Interestingly, the last part of the sentence states that: *«Watch shall be maintained by visual observation, augmented in low visibility conditions by radar, when available»*.

2.2.2 TWR Controller

This position is defined in [6] as being: «normally responsible for the operations on the runway and aircraft flying within the area of responsibility of the aerodrome control tower». In brief, the first responsibility of the TWR controller is to ensure that sufficient runway separation is kept between landing and departing aircraft. Specifically, the TWR controller is responsible of:

1. the landing A/C until the RWY is vacated;
2. the departing A/C, from the holding position for the take-off, until the A/C is handed off to the approach unit.

The TWR is the first contact point for the arriving traffic, right after the approach unit. The TWR issues the "clear to land" instruction (or "clear to take off", for departing traffic) and gives to the pilot information about the weather and wind conditions. The TWR has to be aware of the conditions and of the status of all RWYs. The RWY occupancy status is checked through direct observation and radar ROI indicator on the AGL screen display. The weather information is usually provided through a dedicated monitor (displaying visibility, temperature, wind direction, wind intensity, pressure). Once a departing A/C has left the area of responsibility of the aerodrome, the TWR hands over (i.e. transfers the control of) the A/C to the approach unit.

The TWR controller (in coordination with the approach control unit) is responsible of defining the most appropriate RWYs configuration, that is: «the RWY or RWYs that, at a particular time, are considered by the aerodrome control tower to be the most suitable for use by the types of aircraft expected to land or take off at the aerodrome» [6].

When an A/C has landed and vacated the RWY, the TWR hands over the aircraft to the GND through radio communication, whereby instructing the pilot to change radio frequency and contact ground

Co-funded by the European Union

with the transfer of responsibility4, from the TWR to the GND. The same process is used for the departing traffic (which implies the change of radio frequency instruction and the hand over from the GND to the TWR).

2.2.3 GND Controller

This position is defined in [6] as being: «normally responsible for traffic on the manoeuvring area with the exception of runways». In other words, the GND is responsible for the safety of aircraft that are taxing on TWYs, from and/or to the RWY.

The pilot contacts the GND for the push-back/taxi clearance, and (after the GND's approval) the A/C will be routed through the movement area until it has reached a holding point close to the RWY (then, the A/C will be handed over to the TWR).

The GND monitors and guides all the surface movements, is in charge of communicating to the pilots the taxi routes so as to avoid collisions with other A/C or objects, and minimizing the risk for the aircraft entering an active RWY. The GND assigns priority to A/C (both arriving and departing) for the TWY occupancy.

The GND has several means to determine the position of the A/C within the manoeuvring area:

1. direct observation;
2. the ground radar;
3. the radio communications, as the controller can request to the cockpit to report and communicate the exact A/C position.

The GND may authorize an A/C to taxi an active RWY. This manoeuver has to be coordinated with and approved by the TWR.

2.2.4 A-SMGCS

The Eurocontrol reference document describes the main features and levels of A-SMGCS [3].

A-SMGCS services offer a range of functionalities aimed at improving the safety and efficiency of airport surface operations. Some key features include:

- Surveillance Service: A-SMGCS systems provide real-time monitoring of aircraft and vehicles on the airport surface using radar, multilateration, ADS-B, and other sensors. This surveillance data allows air traffic controllers to have a comprehensive view of all movements on the ground.
- Airport Safety Support Service: Conflict detection and resolution: A-SMGCS tools can detect potential conflicts between aircraft, vehicles, and other objects on the airport surface. The system alerts controllers to these conflicts and provides guidance on how to resolve them, helping to prevent collisions and improve safety. It detects and triggers at least one of the following types of alert such as Runway Monitoring and Conflict Alerting (RMCA), Conflicting

[4] Typically done by transferring the (physical or electronic) flight strip.

ATC Clearances (CATC), Conformance Monitoring Alerts for Controllers (CMAC). The Airport Safety Support Service is using the Surveillance Service, the Routing Service and the input of electronic Clearances.
- Routing service generates ground trajectories for mobiles. In most cases these trajectory points for aircraft are the assigned runway holding point and parking stand, or for vehicles, two positions on the movement area. Routes can be created or modified by the Controller at any time. Routes can be characterised (i.e. planned, cleared and pending route) according to the Clearance given to the mobile. Additionally taxi times are calculated and can be provided for planning purposes to the Airport-Collaborative Decision Making (A-CDM) platform.
- Guidance service provides visual information to Flight Crew or Vehicle Drivers to allow them to follow a defined route. The Guidance Service is using the Routing Service in conjunction with Controller inputs to allow the automated switching of Taxiway Centreline Lights (TCL) and/or stop bars. Additionally, Advanced-Visual Guidance Docking Systems (A-VDGS) can be integrated to provide enhanced guidance in the vicinity of the stands and automated activation of the A-VDGS linked to Surveillance. The Guidance Service improves the movement of mobiles on the movement area and reduces the Controllers' workload.

A-SMGCS services can be integrated with other airport systems, such as air traffic management systems, airport databases, and weather monitoring tools. This integration allows for more seamless coordination and decision-making across all aspects of airport operations. A-SMGCS tools provide enhanced situational awareness to air traffic controllers, pilots, and ground staff by presenting a real-time, bird's eye view of the airport surface. This helps all stakeholders make informed decisions and respond quickly to changing conditions. Overall, A-SMGCS services play a vital role in ensuring the safe and efficient operation of airport surface movements, helping to prevent accidents, reduce delays, and improve overall operational effectiveness.

A Controller Working Position (CWP) is made available to provide Controllers with a Human Machine Interface (HMI) and for some services an Electronic Clearance Input (ECI) means.

2.3 Airport operations at a glance

2.3.1 A-CDM airport

A-CDM (Airport Collaborative Decision Making) is a European concept that aims at increasing airport control and to improve airside performance management, by encouraging information-sharing and creating collaborative decision-making in both nominal conditions and adverse conditions, including disruptions.

The way to implement A-CDM concept at European airports is described in the Eurocontrol documentation [3] and is based on 6 pillars: Airport CDM Information Sharing, a Milestone Approach for the turn-round process, Variable Taxi Time, Pre-Departure Sequencing (see section2.3.2), Airport CDM in Adverse Conditions, Collaborative Management of Flight Updates.

Implementing the A-CDM concept on an airport platform benefits to all stakeholders: Aircraft Operator by reducing taxiing times and fuel consumptions, Air Traffic Control by improving the predictability of departures and therefore runway capacity optimization and slot compliance, Ground Handlers by

Co-funded by the European Union

improving the utilization of their resources and finally Airport Operator by improving taxi environmental performance, punctuality and organization of resources.

2.3.2 Pre-departure sequencing (PDS): How does it work?

PDS is the process by which the overall consistency of A-CDM departure process is ensured. By sharing their information and using common timetables, the various stakeholders (airlines, ground handling, air traffic control and airport operator) optimize the management of their departures. Figure 3 illustrates this process.

For each departing aircraft, the airport slot is taken as a reference for the departure time. The airline must file a flight plan to be able to use this departure time. If the flight crosses a regulated sector or if the destination airport has limited capacity, it could be regulated by the NMOC and receive a NMOC slot. The airline must also notify any delay other than ATC delay, by sending a Target Off-Block Time and by updating the flight plan if necessary.

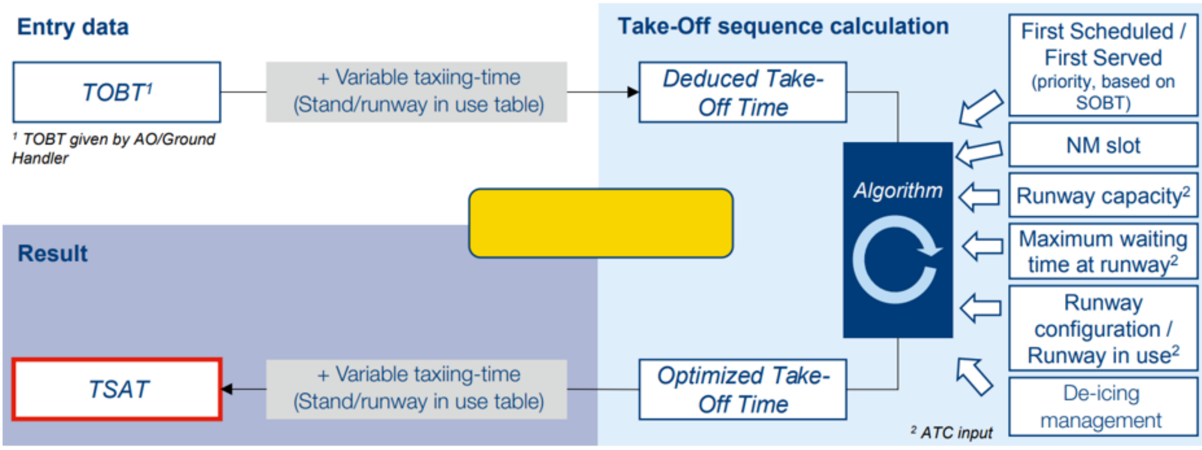

Figure 3 : Example of Pre-Departure Sequencer algorythm

The PDS system calculates an authorized off-block time for each flight (TSAT), taking into account these various times, in addition to local ATC capacity constraints, and an off-block pre-departure sequence for all the aircraft.

2.3.3 Resources and capacity optimization

The use of a pre-departure sequencer taking all the constraints applying on departure flight on an airport allows to optimize:

- Runway capacity, by "feeding" the runway threshold with enough departing flights. Attention must be paid not to let too many departure flights leaving the parking stands at the same time to avoid taxiway congestion.
- Parking stand capacity, by transmitting the TSAT (Target Start Up Approval Time) information to all systems. TSAT id The time provided by ATC considering TOBT (Target Off BLock Time), CTOT (Computed Take Off Time) and/or the traffic situation that an aircraft can expect start-up / push back approval. This data is usually used in the parking stand allocation management

tool. It allows to predict if a flight is able respect its turnaround time, and therefore to re-allocate if needed the next flights planned on the same parking stand resource in case of conflict, in order to avoid aircraft waiting on taxiway due to the occupied stand. Decreasing taxi time on arrivals represents an operational situation of interest to reduce emissions and to improve punctuality.

- En-route capacity, by sending updates of aircraft target take-off time updates to the Network manager through departure information messages (DPIs). The Network Manager takes into account every target take-off time of all flights departing from an airport in the scope of Eurocontrol regulation and manages the En-route capacity based on these data.

2.4 Studied Airports specificities

This section presents the results from our interviews and workshops with ground operations stakeholders at three major European major airports: Paris-Charles de Gaulle (CDG), Amsterdam Schiphol (AMS) and Frankfurt (Fraport) airports. The stakeholders included airport operation and innovation managers, a ground handling quality and sustainability manager, an A-SMGCS and autonomous ground movement expert and an apron controller.

Basically, the three airports involved are quite different from one another. CDG is widespread in between two runways' doublets and two main terminals, resulting in a long network of taxiways and service roads, often with parallel taxiways. Moreover, CDG has a specific apron control to handle pushback and taxi operations in the parking areas, which is not the case in the other airports considered and induces a higher need for coordination between operators and a higher use of radio. AMS is mostly characterised by its 6 runways that are to be used fairly over the year and its 'circular' taxiways around the main terminal. Fraport at the opposite has a short routing network serving the terminals gathered around the main runways, resulting in a small degree of freedom to manage disruptive traffic.

However, as discussed in the following sections, they would all benefit from a higher level of automation and human automation teaming.

2.4.1 Paris-Charles de Gaulle Airport (CDG)

Ground operations at CDG are a trade-off between runway pressure and taxi time with an average taxi time of 15 and 10 minutes for departures and arrivals, respectively, and allowing about 9 aircraft queuing on runways' holding points (for each departure runway). However, traffic congestion is substantial throughout the year, mainly due to parking stand occupancy rate generating hundreds of gates hold per year (mostly during summer season). The congestion has a detrimental effect on safety and sustainability (i.e. noise and fuel consumption). Reducing the number of aircraft waiting on the taxiways should improve the punctuality, safety and sustainability, key performance indicators such as contact parking rate, punctuality or noise levels and fuel consumption, that are badly impacted by traffic congestion. In the light of these elements, we identified scenarios where current ground operations could benefit from automation.

Gate holding at CDG has a significant impact on flight arrivals and other ground operations. During our interview with an airport procedure engineer in the control tower, the participant was distracted by an immobilised aircraft on the taxiways. The aircraft had not moved for more than 10 minutes. This reminded the engineer of an anecdote about an accident on one taxiway used in winter for de-icing where an aircraft on hold on this taxiway was hit by a wing of another aircraft taxiing by. From this interview, several scenarios emerged in which automation could *"smooth the traffic and avoid accident prone situations*". Basically, any aircraft stopped in taxiways, even in dedicated spots, is a safety threat for other traffic since it changes the normal taxi rules. In this specific case of the anecdote, an aircraft stopped on this particular taxiway involved a restriction in the wingspan of traffic passing-by. This led us to discuss taxiing speed regulation to avoid holding aircraft on the taxiways and AI-based remote holding solutions, both for arrivals and departures.

At CDG, the Apron control manages, amongst others, the aircraft taxi until they are allocated to parking stands according to the requests. Next to the Apron control position in the tower, the Air France Hub stand managers handle incoming movements and parking requests from the airline. Even if a digital strip system is used to feed information to the A-CDM, paper strips are still used to schedule movements on the apron. For each aircraft arriving and leaving the apron, a paper strip is printed. Most of the unexpected movement requests is centralised by the Air France Hub which forwards the requests to the apron controller with a handwritten paper strip left on a special stack on the controller's workspace. Depending on the urgency of the requests and the current workload on the apron, the controller reserves the right to reject the movement requests. The apron controller is also responsible for authorising pushbacks.

Pushbacks are performed by ground handlers upon pilots' requests. During the pushback phase, tug drivers communicate visual aircraft surroundings inspection to the pilots, and they negotiate with the pilots the pushback timing and angle. Beyond the pushback operation, the negotiation between the ground handlers and the pilots is essential, as the delays from both handling and flying crew will impact not only the current flight but also the following flights which are allocated to the same handling team. That being said, ground handlers are used to unexpected situations as they are able to dispatch their resources up to 15 minutes before they are needed thanks to GPS monitoring of all their vehicles and the real-time data updates from the airport A-CDM. That makes the ground handling operations highly flexible and capable to mitigate potential delays.

However, automation could benefit to specific ground handling activities. For instance, pushback operations could be improved by automatically computing the best pushback strategy (i.e. angle, force, ground topology, weather, aircraft weight, etc.) and provide pushback clearances under human supervision. Another way to address the challenges of ground handling could be providing autonomous vehicles to reach gate locations, perform pushbacks and luggage transfers between terminals when needed.

2.4.2 Amsterdam Schiphol

Due to its location near the sea, Amsterdam Schiphol (AMS) is often subject to adverse winds and sudden wind direction changes. Therefore, runway mode operation (RMO) changes are frequent, much more frequent than at CDG for instance. RMO changes are planned 45 to 30 minutes ahead and have a significant impact on the traffic in AMS. The transition from one RMO to another can lead to opening a new traffic flow to accommodate the new RMO while the current RMO traffic flow is still being operated for the aircraft already taxiing on the platform. RMO changes are too complex for the new routes to be planned in advance especially since RMO can change as aircraft are already taxiing to the gates with a route that can last for 25 minutes. ATCO can negotiate with pilots whether to have a RMO change while aircraft are already taxiing but this has a significant impact on the ground handling operations. Managing both traffic flows during RMO changes is challenging for ATCOs, pilots and ground handlers.

To support RMO changes, current traffic flow, inbound and outbound data could be used to compute a new traffic flow for RMO changes and provide the stakeholders with optimal new routes for increasing the capacity and gate schedule for more efficient ground operations. In addition, the AI could supervise some routes until the new RMO is in place to mitigate the effects of RMO changes even more.

Remote holding is usually useful for arrivals when parking stands are unavailable. Usually, ground control gives clearance to holding locations referenced in operational procedures. Holding procedures can increase ground control workload. For instance, the movement of an A380 aircraft during daily operations may be challenging. As we were told by a stakeholder from AMS, the movement of an A380 aircraft could lead to the immobilization of 4 taxiing EasyJet flights to remote holding positions at AMS. These situations are difficult because air traffic controllers need to remember that they gave holding instructions to allow aircraft to resume their routes.

Remote holding procedures may also introduce traffic issues. Aircraft may have to taxi against the traffic flow if they are still on hold when runway mode of operations changes. This will result in increasing controllers' workload to handle the traffic. Non-active de-icing pads are conveniently used as holding points and potential de-coupling points for towed aircraft, but they are not included in the manoeuvring area and thus supervised by another operator on a different radio frequence. Planning between areas with different authorities may increase controllers' workload to coordinate with pilots and other controllers. Given the challenges that remote holding procedures bring, it is unclear whether remote holding procedures could be also useful for outbound early departure flights to vacate parking stands faster.

One way AI could address these challenges is to compute and suggest on-the-fly bypassable holding points for delayed gate access and towed aircraft decoupling. The holding point location would be computed from runway mode operation, traffic, bound schedules and the airport infrastructure data. However, it is essential to constrain the AI to facilitate human operator handover when needed. For example, the AI could offer a degraded mode where only the most convenient holding remote locations in the airport operations manual are provided.

Taxiing procedures could also benefit from AI support and autonomy. For instance, performance of runway exits after landings could be increased by computing the best runway exit for each aircraft based on runway operations history. Furthermore, runways crossing could be managed by AI by providing the right moment for aircraft to cross runways all together.

One challenge related to take-off procedures is the lack of shared awareness. For instance, the take-offs ordering sequence which is built on-the-fly by controllers as pilots request take-off clearances, is not shared with other stakeholders. To provide more ground operations predictability, AI could optimise the take-offs ordering sequence for controllers using operational procedures and CDM runways data, then share it with all the stakeholders.

Finally, pushbacks and engine startup procedures could also benefit from AI support. For example, it was reported that a non-optimal pushback could block up to 10 parking stands at AMS. Based on inbound and outbound schedules, AI could provide finer control of pushbacks, such as short or long

Co-funded by the European Union

pushbacks, which would offer more flexibility for aircraft parked beside and optimise parking occupancy. Another means to optimise parking occupancy is to improve start up engine procedures which can last up to 10 minutes. Currently, the only provided information to plan engine startup is the remaining time to take-off (i.e. "time left towards the runway"). More accurate engine start-up time could be provided by the AI.

2.4.3 Frankfurt airport

The main challenges in Frankfurt Airport (Fraport) are the limited space to manoeuvre aircraft and the complex dependencies of the runway system which have a critical impact on ground operations. Since the number of taxiways is limited, inbound and outbound aircraft have to share common routes on the platform making the traffic quite dense at Fraport.

Because of the reduced space, parking occupancy is critical at Fraport. The number of parking stands is inadequate for the airport capacity, which results in towing aircraft back and forth from the north to the south apron to free gates as needed and increasing the traffic density even more. Service roads are located close to the parking stands which makes service vehicles subject to jet blasts. In addition, service roads and taxiways intersections are common at Fraport and prone to accidents between service vehicles and aircraft.

Since the parking stands are limited and the traffic usually dense, it is critical that companies and aircraft observe their target off block time. However, when delays occur, finding solutions to maintain flowing traffic is challenging. Arriving aircraft can be put on hold. Remote holdings occur close to the apron area in taxiways that intersect the main taxiways along the runways. Monitoring the traffic at all times is essential to locate the best remote holding positions when needed. However, aircraft holding at the best possible location may have to vacate the taxiway to keep the traffic flowing, if the departure delay at the gate is too long.

Pushback strategies are operationalized to optimize gates turnover and flow on the aprons similarly to CDG. Finally, when a gate cannot be vacated quick enough for the next flight, gate change is the last option. Although done at the last minute, there must be enough time to allow passengers' rerouting through the airport.

In Fraport, there is a need for parking stands reallocation, rerouting and pushback guidance support. Given the current traffic, AI could help setting the best remote holding locations when needed and finely schedule empty aircraft movements to vacate the gates for arriving aircraft. It could also provide more traffic predictability to apron controllers with aircraft route optimization for reducing possible traffic conflicts. Furthermore, a checkpoint system for aircraft on the taxiways could help control the traffic flow on Fraport even though speed guidance is not feasible because of liability. Finally, helping controllers to choose the right pushback strategy to optimise space would be helpful. For example, the AI could help to decide which axis of the three an aircraft should be pushed back to or the best approach to synchronize several pushbacks at the same time.

Even though AI help appears useful in certain situations, the people interviewed shared their concerns on liability issues (see chapter 4.3), and on the possibilities for the operator to overrule AI decision or put constraints on routings for given vehicle.

Co-funded by the European Union

2.5 Conclusion on ASTAIR scope

ASTAIR will consider vehicles, aircraft and tow tugs, in the movement area, from gate to runway holding point for departure and from runway vacated to the gate for arrival traffic. Concerning a departure flight, A-CDM will be the entry point to potentially modify TOBT up to 5 minutes before actual time and it is delivered to TWR control following the computed departure sequence. On the other hand, ASTAIR will consider estimated time of arrival of aircraft confirmed 10 to 15 minutes in advance thanks to AMAN tool, in addition assigned parking can be modified up to 5 minutes before Estimated time of Arrival (ETA). ASTAIR will regularly compute conflict free routes for the coming 20 minutes timespan and recompute when needed. Conflict resolution will be ensured with speed regulations on the trajectories given to the vehicles. Even though all trajectories are computer by ASTAIR AI, the human operator can will have the possibility to specify various constraints or input new information to AI in order to facilitate the ground movements and handle specific operational events.

Our workshops revealed several specificities of each airport but also similarities in the operations and the concerns about automation. All airports studied in our activities displayed very different layout and context that impacted the operations and raised different concerns for automated ground operations.

A common impediment to smooth ground operations and airport capacity limitations is the management of parking stands, even more important than the runway capacity. Indeed, parking stands problems have impacts on taxiing. The airport layout has an important impact on the strategies to mitigate the taxi issues. A wide routing network like CDG gives a lot of possibilities to delay aircraft while taxiing until the issue is solved whereas at Frankfurt airport the lack of parallel taxiways forces the controller to find holding spots for aircraft on-the-fly. But each configuration would benefit from a computation of vehicles routing deconflicted with speed management, including full stop and go, to solve gate occupancy issues and get the aircraft arriving right on time.

Another common feature on the three airports is related to parkings arranged along a single taxilane. This type of configuration force the controller to synchronise correctly the push backs to avoid having aircraft blocked in a dead end waiting for other aircraft to perform push backs. In the same manner, a system computing conflict vehicles routes for the coming 20 minutes would give the operator some help on pushbacks synchronisation. Then, during taxiing, the use of temporary holding points to solve conflict on ground is also a shared approach by the ATCOs but each platform has specificities. AI could help choose the holding locations from a set of predefined spots, and potentially raise awareness on specific restrictions imposed by these operations to reduce safety issues. AI could also go as far as proposing new holding locations on-the-fly for smoother operations. In the same manner, ground operations have different infrastructure that can host Taxibots during coupling and uncoupling phase which could create additional complexity and AI could help managing these spots as well.

Automation failure, final decision and handover from AI are also recurrent questions raised during all interviews we had. It appears that particular attention shall be paid to inputs given to AI as well as its tuning to particular operations of each airport. Operational rules that are due to technical constraints such as wingspan or vehicle weight for instance must obviously be considered in the routing proposed by AI. But these operational rules are not only due to technical limitations but are also due to human cognitive limitations. It should be possible to find more optimal routing without the latter limitations.

EUROPEAN PARTNERSHIP
Co-funded by the European Union

Playing with them could lead to findings in the recovery process in case of automation failure, but the scenario still needs to be worked on.

Although the management of dead-end taxi lanes in apron and limited space for remote holding is critical for Fraport, it is also a common consideration at CDG and AMS. Therefore, one of the ASTAIR use cases will be dealing with holding. The multi agent system should also manage synchronisation of pushbacks but it may be a lower priority for investigations.

Regarding ground handling, we identified a need for better mission planification where AI could optimise human and material resource allocation if pooling is introduced.

Another specificity for Fraport is the responsibility of taxi phase given to airport manager, and not ATC, until the runway. On the contrary, at CDG there are different operators in charge of apron and ground control. It seems obvious that ASTAIR will be far more efficient if it manages traffic from the gate to the runway and back. Potentially, on runway side it could be interesting to use AI to prepare an optimised departure sequence, wake vortex separation wise, for the tower control.

The change of runway configuration mode is very frequent and challenging at AMS but rare and easier to handle at CDG and Frankfurt. However it is an interesting use case on AMS since the taxi times are quite long, the re-routing of already taxiing aircraft could be quite challenging.

In addition, although full towing (inbound and outbound) may not be the goal to achieve for all airports, the evolution of jet engines shows more and more that taxiing on engines is not a desirable future for efficient ground operations and AMS has full towing as a target in its roadmap.

Finally, another consideration emerged during the discussions: the ground workers conditions in terms of noxious emissions and noise nuisances is increasingly important for airports management. Autonomous engine off taxiing could help by facilitating engines start up farther away.

Co-funded by the European Union

3 Use cases

In this section, we describe height Use Cases (UCs) that were elaborated during the workshops with stakeholders and the ASTAIR Consortium members. The use cases illustrate how some tasks involved in airport ground operations could be automated within the scope of the project. For each use case, we indicated in the main scenario line how specific elements could be automated and we indicated the possible level of automation using the EASA levels described in section 1.3 in green when applicable.

These use cases will be considered in the design of solutions and the validation activities within the ASTAIR project, but not all of them will be validated in the Real Time Simulation (RTS). The validation plan will detail how the UCs will be used, and which ones will be demonstrated according to the validation objectives of the project. Note that these use cases are preliminary and will be adjusted and expanded in the Deliverable D1.3 Concept Outline.

3.1 UC1: Taxibot departure

Description	This use case describes a situation with a departing aircraft using a taxibot.
Actors	Taxibot Operator, Pilot, GND ATCO, TWR ATCO
Preconditions	The aircraft (A/C) is preparing to leave its gate for departure. Taxibots are available.
Postconditions	The pilot contacts the TWR, TWR clears the A/C for take-off. The taxibot is driven back to the next designated area by its taxibot operator. Potential delay is removed due to the automated use of taxibots. Pilot is not required to contact TWR (done by AI).
Assumptions	It is assumed that the stakeholders will use new ASTAIR tools to manage automated ground operations.
Scenario including possible levels of automation	**1. Up to a sufficient time for AI to respond before departure:** - The GND ATCO validates the flight information (1A) - AI computes conflict free routes for all aircraft and taxibots (3A) - AI allocates and routes taxibots (3A) - The taxibot operator validates the allocation (1A) **2. When pilot is “ready to push”:** - The pilot calls the GND ATCO to ask the push-back clearance. - The GND ATCO validates information and authorizes a pushback (1A)

Co-funded by the European Union

	- The GND ATCO gives authority to AI to route and guide the aircraft with the taxibot to the runway (3A) - The GND ATCO clears the A/C for pushback. (1A) - The GND ATCO monitors the AI system. **3. During taxiing:** - AI provides directions clearances along with speed profile or timing indications to the pilot and monitors the progress (3A). - If the aircraft needs to start engines up, AI notifies the GNC ATCO that an action is required, in advance and at the appropriate time. GND ATCO issues the clearance to startup engines when appropriate (2A) - Pilots performs a startup following the AI guidance (1A) **4. When reaching the runway holding point:** - Aircraft is transferred to TWR by AI, once the aircraft reaches the RWY holding point (3A) - AI prepares the departure sequence by strategically managing the distribution and order of aircraft at the holding points (3A).
Expected impacts	Reducing congestion on airport surface movement which would reduce delays in aircraft departure and have positive impact on the environment in a scenario where taxiing operations are handled by taxibots efficiently. Improved predictability of the departure sequence based on the speed profiles and centralized routing. Less workload for the GND ATCO supervising the taxiing for the departure. Better environmental performances due to use of taxibot.
Expected use for the research activities	This use case demonstrates the concepts of ASTAIR and will be used to design the AI, the Interactions and build the real time demonstrator for ASTAIR to collect feedback.

3.2 UC2: Normal operations with re-scheduling

Description	This use case describes a departure situation with rescheduling of a departing aircraft due to delays (for instance, luggage or passenger)
Actors	Taxibot Operator, GND ATCO, Pilot, Airline Operator

Co-funded by the European Union

Preconditions	The aircraft is preparing to leave its gate but will be late with respect to its indicated TOBT.
Postconditions	The aircraft is given a new EOBT, a tug and a conflict free route by the ASTAIR system.
Assumptions	It is assumed that the stakeholders will require new ASTAIR tools to manage automated ground operations. A new indicated TOBT is provided to the pilot by the A-CDM and is known to the ASTAIR system.
Scenario	**Pilot indicates a 10-minute delay before departure** - AI updates the conflict free routes for all vehicles (3A) - AI re-allocates and re-routes tug accordingly if required for deconflictions (3A) - GND ATCO and Taxibot Operator are notified about the changes made to the routes that were previously validated and acknowledge them (2B)
Expected impacts	Better service quality (contact parking rate), better resilience of the system and possibly better fuel efficiency and predictability as other routes could be further optimized. Less workload on the GND ATCO to adapt to the situation. Cost Efficiency for Airline Operator.
Expected use for the research activities	This use case will be used to consider changes in A/C and tugs path plan occurring both in the Path Planning Algorithms and Interaction Design.

3.3 UC3: Arriving traffic without parking

Description	This use case describes an arriving aircraft whose planned parking location will not be free at the expected time.
Actors	GND ATCO, Pilot, Airline Operator, Airport Manager
Preconditions	The planned parking location of the aircraft is not available and will not be ready for use at the planned time.
Postconditions	The aircraft is parked with an assistance of an AI.
Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	**Between 15 minutes and 5 minutes before an arriving aircraft land**

EUROPEAN PARTNERSHIP
Co-funded by the European Union

	- GND ATCO validates information / AI computes a conflict free route (1A) - AI predicted taxi times show that the parking will not be free for the arrival flight (3A) - AI informs Airline Operator, Airport Manager and suggests another parking if possible. Airline Operator and Airport Manager refuse to change. (2A) - AI informs the GND ATCO of the change and offers several routing strategies including holding far from the parking to reduce incidence on future traffic, hold close of the parking or taxiing slowly. GND ATCO can inspect, choose and refine a solution (2A) **Pilot calls the** GND ATCO **for taxi** - GND ATCO gives authority to AI to route and guide the aircraft according to the planned solution (3A) - GND ATCO can improve the system performance by adding guidance and instructions, due to his/her expertise in this field (2B) **Gate is available** - AI updates the plan and sends guidance to the aircraft to reach the parking position (3A)
Expected impacts	Reduce congestion around the predetermined parking area, improve fluency of ground movement and processes. Improved resilience to operational events when parking location is occupied possibly when an aircraft arrives earlier, or the aircraft arrives on time, but the departing aircraft will occupy the parking location longer than anticipated.
Expected use for the research activities	This use case will be used to design and assess new interactions enabling users to finely tune the system behaviours to improve its performance. It will also be used to study the capabilities of Path planning algorithms to consider unexpected situations.

3.4 UC4: High level taxi strategy tuning

Description	This use case describes a situation in which case an operator can adjust the AI routing strategy to respect strictly or not the

	airport rules (e.g., preferred taxiways directions in specific configurations)
Actors	Airport Manager and/or Head of Ground Control activities supervising the system at a strategical level
Preconditions	The system is configured in an initial condition
Postconditions	The system is adjusted to respect the new conditions.
Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	**The traffic is expected to decrease in 15 minutes** - The user reduces the conformance level of the AI to current operational procedures including the directions of taxiway. (1A) - AI compute new routes with the new constraints (3A) **The traffic is expected to increase in the next 15 minutes** - The user increases the conformance level of the AI to current operational procedures (1A) - AI compute new routes with the new constraints (3A)
Expected impacts	Adjust the performances of the system (Predictability, Environmental performances) to Human performances.
Expected use for the research activities	This use case will be used to study the multi agent path planning algorithms' behavior and performance in different contexts.

3.5 UC5: Automation failure

Description	This use case describes a situation in which the AI is no longer able to compute a conflict free solution.
Actors	Taxibot Operator, GND ATCO, Pilot
Preconditions	AI is not able to find a feasible solution that satisfies all constraints (i.e. non-existence of conflict-free solutions that enable all vehicles to reach their destinations within required time windows).
Postconditions	The AI works again, and aircrafts have been routed

Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	- AI warns that no solution can be found and gives GND ATCO the remaining time of the latest conflict free solution that is still applicable (3A) - GND ATCO and Taxibot Operator analyze the on-going situation (1A) - Aircraft that have conflicting routes are warned (2B) - GND ATCO performs the routing manually (1A). - Once AI finds a solution, aircraft are transferred back to AI by the GND ATCO (3A)
Expected impacts	Decrease the overall airport performances and increase the operator workload without compromising safety.
Expected use for the research activities	This use case will be used to design interactions that enable users to recover from failure and collaborate with the AI.

3.6 UC6: Runway mode of operation modification

Description	This use case describes a situation requiring changing the runway mode of operation.
Actors	Taxibot Operator, GND ATCO, Pilot
Preconditions	Several departing and arriving aircrafts are scheduled and using the taxiways. Some are using taxibots.
Postconditions	A new routing plan is created, the arriving aircrafts could reach the gates and the departing ones could change their routes accordingly.
Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	**45 minutes before the change** - The GND ATCO specifies in the system that a runway configuration change is planned (1A) - AI computes new routes with the new constraints and shows which aircraft is the last to use the current configuration (3A)

Co-funded by the European Union

	- If an aircraft must change its route while taxiing, the GND ATCO ask the pilot to accept the change or not. - The GND ATCO then validates the new routes or keep the previous ones (2A) - Taxibot Operator is informed of the changes (3A) - AI adjust the routes to the GND ATCO and pilots' decisions (3A)
Expected impacts	Reduced workload for the GND ATCO. Better predictability.
Expected use for the research activities	This use case will be used to study the capabilities of Path planning algorithms to consider such situations and interactions to specify a change in runway mode of operation.

3.7 UC7: Departure remote holding

Description	This use case describes a situation in which an aircraft is ready to depart before its expected time slot and remote holding procedure is used.
Actors	Taxibot Operator, GND ATCO, Pilot
Preconditions	An aircraft is ready to depart before its TOBT time to free a parking slot or possibly depart earlier. The taxibot is ready to tow it.
Postconditions	The aircraft is aligned for takeoff
Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	Uncoupling and takeoff - AI deals with departing flights for which Network Manager issued Computed Take-Off Times (CTOT-slots). (2A) - AI sends the departing flight to a remote holding location close to the scheduled runway or to an intermediate holding point in the taxiway system, at which the aircraft could wait. It updates the activity sequence of the departing flight accordingly. (3A)
Expected impacts	Improved resilience to operational events when parking location vacated earlier and possibly departing aircraft leaving

	the platform earlier. Possible economic benefits for the TaxiBot Operator depending on the decoupling location.
Expected use for the research activities	This use case will be used to study the capabilities of Path planning algorithms to consider such situations.

3.8 UC8: Arriving flight with technical issue

Description	This use case describes a situation in which an arriving aircraft faces an emergency at landing requiring inspection escort the aircraft to the parking.
Actors	Tug operator, GND ATCO, Pilot, Emergency Services (Firemen)
Preconditions	An arriving aircraft warns the ATCOs that an engine has a problem and other aircraft are taxiing on the platform.
Postconditions	The aircraft is parked and the traffic on ground resumed to a computed plan.
Assumptions	It is assumed that the stakeholders will require new tools to manage automated ground operations.
Scenario including possible levels of automation	When the aircraft lands - GND ATCO defines the aircraft as higher priority to avoid any speed regulation on this one and specifies manually the route. (1A) - AI stops conflicting aircrafts on temporary holding points or finds new routes (3A) - GND ATCO can manually indicate that some stopped or rerouted aircraft can resume their routes after the high priority aircraft passed, to improve the overall AI performance (2B) - Once the aircraft reaches the parking location, the AI gives routes to holding aircrafts (3A)
Expected impacts	Reduce cognitive workload for the GND ATCO, improved resilience of the system.
Expected use for the research activities	This use case will be used to design interaction enabling users to improve system performance in challenging situations and

	also to consider the use of user defined trajectories in the path planning system.

Co-funded by the European Union

4 Discussion of levels of automations and identified challenges

In this section, we describe the findings gathered during our workshops related to the ASTAIR concept performances with increased automation in airport ground operations described in our use cases. We articulate our findings according to three main themes that will be studied with the ASTAIR project: Human-Automation Teaming, Multi Agent Path Planning and Liability.

4.1 Human-Automation Teaming

Several hopes and concerns regarding human-automation teaming and the impact of the ASTAIR concept on Human Performances were raised during our workshops.

First, we identified that using higher levels of automation on ground operations could shift the roles of humans toward supervisors as illustrated in the proposed use cases. Such a shift poses specific challenges in terms of training but also in maintaining skills and situation awareness. One participant suggested that *"Getting tasks done (validating them) enables commitment and skills maintenance"*. This is reflected in our cases by usually having the operator validate the information and the plan before transferring the responsibility of the aircraft to the AI. Beyond what tasks could reach specific levels of automation, another interesting point raised is when to use the automation. Another participant suggested that: *"During the peak time, ATCOs are very concentrated and efficient. Incidents happen when traffic is low"*. This suggests that we also need to study when high levels of automation could be most beneficial to the overall system performance.

Other concerns raised were specifically focused on user confidence with the AI and the system in general. Participants in the workshop expressed concerns about how to handle situations in which the AI could fail. This leads to specific questions such as*: how to hand over to humans? If manual actions are required, does the operator need to be an ATCO in case of failure?"*. For some, using automation was a way to pack more traffic and as such in case of failure, this would cause high workload on operators taking over. Such results highlight the need to design and assess interactions enabling humans to assess the status of the AI and facilitate handover when necessary. Specific recommendations were made toward having the AI using human-like procedures such as known preferred directions or standard holding points to facilitate handover if necessary.

Collaborations between human operator and AI is a particularly challenging design aspect in our view. Our workshops revealed that human expertise is extremely important in many situations that have possibly multiple solutions and that airports have very specific procedures depending on numerous factors such as weather, traffic, types of aircraft or individual preferences. We will study how to design interactions enabling cooperation between humans and AI such as when an aircraft is routed via the AI on the taxiway but also requires a human security check and clearance or starting up its engines during taxiing. In addition to this cooperation, we also want to study the possible benefits from human expertise not only to take over when there are events that require human handover from the AI but also to actually collaborate with the AI to improve the system performances. Specific use cases such as the arrival without parking illustrate how a human operator with a strong expertise on the activities of the airport and possibly knowing data that the system cannot detect could guide the AI to achieve better performance.

4.2 Multi Agent Path Planning

Coupling – decoupling locations: The AI solutions based on multi-agent path planning which consider both the path planning of the aircraft and taxibots require defining coupling and decoupling locations on airport layouts in addition to existing nodes representing the parking locations, runways, and other origin and destination points for the vehicles. The coupling and decoupling areas require also allocating a dedicated time while coupling or decoupling operations are being completed. Depending on the infrastructure of the airport allocation of decoupling and coupling locations might become a challenge. If the capacity of the airport is not sufficient to allocate coupling and decoupling locations in convenient or optimal locations the traffic at the airport might be affected negatively. In addition to limited capacity, frequency of flights, depending on the airport infrastructure, might lead to the aircraft queues in front of coupling and decoupling locations. The interruptions in the fluency of these processes can also be caused by the heterogeneity of the aircraft fleet in terms of aircraft types and sizes. When a large body aircraft is followed by a small aircraft while approaching to a coupling or decoupling location, the following aircraft has to arrange its speed to maintain a safety distance, and these types of scenarios might increase the cycle times in inbound and outbound processes. Simulations of queueing models were evaluated in AEON project on the high-level using probability distributions of aircraft arrivals while keeping track of safety distances based on arriving aircraft types and evaluating parallel and serial structures of decoupling locations. An example of a challenging case related to this situation has also been mentioned by Usher AI when a 4EJ aircraft waits because of an A380 blocking all others. On the other hand, given that the infrastructure of an airport is suitable for adding coupling or decoupling locations to optimal places, (i.e. decoupling locations that do not block each other and which are close to the runways) which are in line with the airport traffic, i.e. queueing models allow maintaining a fluent chain of operations, solving this model using AI is technically feasible and environmentally beneficial. Thus, while for the airports with limited capacity this can be a challenge, for the airports with suitable infrastructure it is technically feasible.

Remote holding: Given that AI could create unlimited holding points to be used in the optimization algorithm, which is mentioned by Usher AI, AI could redirect the aircraft to remote holding locations and find conflict free paths. In the case that when remote holding locations are assumed to be unlimited, solving this case may be less challenging. The challenge for AI may still come from the existence of too many conflicts with other aircraft or vehicles. In real life the number of remote holding locations or the capacity of parking at those locations is expected to be limited. As mentioned by Usher AI, holding locations at AMS can host at most 5 aircraft with different sizes and wingspans. In this case AI should also check the capacity and availability of the remote holding location before redirecting an aircraft to that location. While this is technically possible, when there are no remote holding locations available, generating a solution using the remote holding approach will not be possible every time. Apart from these, using the deicing pads as holding locations brings the challenge of maneuvering, as Usher AI mentions that de-icing pads are not part of the maneuvering area and using them for aircraft holding requires more coordination. Also, sending too many aircraft to remote holding locations would require the frequent change of Runway Mode of Operation (RMO) and this would create more conflicts for the flow of future operations as mentioned by Usher AI. This is also a challenge for the AI since it increases the complexity of the problem and creates potential cases of infeasible operational plans.

Data quality: In a fully automated system (3A level) where the availability of supporting equipment i.e. the tugs and stairs is ensured in advance by tracking the changes in the main plan. In other words,

Co-funded by the European Union

detecting the locations of the available equipment and the times when supporting equipment will be required at the activity locations and planning the allocation of these resources based on the changes on the main schedules would be technically possible using AI and adhering to AI guidance using autonomous vehicles or AI guided equipment in a fully autonomous airport. In a 2A level automation, when the human operator needs to check whether stairs are available in which case the duration of ground handling process will depend on the availability of the equipment and human's estimation of the duration of the turnaround process, AI solutions can succeed only when the human operator provides the accurate information on time. Given that all the input and constraints are existing in the information system, AI would technically be capable of generating the best action plans unless there is an infeasible solution that makes the delays on activities unavoidable.

In conclusion, when the use cases defined in Section 3 are considered, the technical feasibility and challenges of dealing with these cases both from the AI and practical perspectives can be outlined as follows: Using taxibots requires planning the routes and assignments of taxibots in addition to planning the paths of aircraft fleet. Given the fact that the number of available taxibots is limited and there are frequent flights that requires taxiing in inbound and outbound processes during the day, reusability (reallocation) of taxibots should be planned carefully by the AI in real time. In a scenario where it is assumed that there is an unlimited number of taxibots or tugs, or where they are not used at all, the aircraft can leave its location immediately based on the plan generated by only considering the departure and arrival schedules and it is easier to deal with, from the perspective of AI. However, the limited fleet of taxibots and generating the plans by also considering the availability and movements of taxibots might require adding extra waiting times for the aircraft and it becomes more challenging to prevent delays in departures or arrivals.

A practical challenge is allocating extra locations at airports for coupling and decoupling operations of taxibots as stated by Usher AI. The capacity of the airport might not allow to add these locations to optimal places. However, this is not always the case. Depending on the airport, suitable locations could exist. Both for the AI and airport operators, the aircraft queues in front of decoupling locations bring new challenges to deal with. With the right infrastructure that allows optimal allocation of decoupling locations and using the support of AI in dealing with queueing models, this issue is not impossible to deal with but airport dependent. In the future, while building new airports, the layout and infrastructure can be designed by also considering the requirement of these areas, due to the anticipation that taxibots will be used more at airports in the future.

Remote holding solutions require holding areas with enough capacity and which do not have disadvantages related to maneuvering, at the airports. Also, frequent use of remote holding can create more conflicts for the airport traffic and might require replanning of a larger group of agents in the system which creates challenges both for the AI and airport operators.

Data quality in the information system is another factor that defines the success of AI solutions, human – machine collaborations and practical operations. Changing RMO might be one of the most challenging cases in practice and for the AI. Even though the suggested algorithms are able to respond to changing RMOs, if many of the ongoing events will be affected by replanning, communicating the new information to all entities and quick adaptation to these changes could be difficult in practice. It could also be challenging for the AI to find feasible alternative solutions in complex scenarios. Although the workload of the controllers is expected to be reduced by automation of configuration of the runways it depends on the complexity of the variables that have an impact on each other and the success of AI and operators to respond this in an agile way.

The remaining cases, rescheduling and taxi strategy tuning, are technically possible for AI, given that alternative feasible solutions exist. When AI failures stem from non-existence of a feasible solution with respect to the defined constraints, the response of the Human-AI system would be to find a solution by violating some of the constraints in which case this violation would usually be on the time windows that would cause delay. It might help to set distinctive classification of constraints as the ones that can never be violated (strict) or the ones that can be violated in such cases although not desired (non-strict). Definition of soft constraints can allow AI to offer alternative solutions when it fails to find a feasible solution for the problem with hard constraints or gives the operator the opportunity to act upon finding an alternative solution considering these facts. In other cases, AI can fail to find a solution quick enough to be produced and communicated to all agents in real time at the occurrence of unexpected events, even though a feasible solution exists. This is due to the fact that the path planning problem is NP-hard and adding many constraints related to airports makes it more complex to solve and depending on the complexity level and the size of the dataset it might not always be possible to respond quickly in real time situations. In these cases, the operator can take over the decision-making role with the expectation of providing a quick and accurate action plan based on human experience. Another option could be using intuitive algorithms which focus less on solution quality but can produce feasible solutions quickly, as fallback solutions for the main AI solution.

4.3 Liability

One of the integral aspects of the project is to prove its feasibility in terms of liability implications across stakeholders. Therefore, one of the ASTAIR validation objectives is to ascertain that the ASTAIR does not introduce unacceptable liability risks for actors and stakeholders.

In order to address any potential risks, the following preliminary success criteria were developed:

- Identification of key new liability risks for all actors and stakeholders involved in defining, developing, and implementing the concept, according to the level of definition achieved at various validation stages.
- Identification of suitable measures in design, organisation, and policy to mitigate identified risks.
- Positive feedback from AB stakeholders on the proposed concept or suggestions for alternative enhancements.
- Ensuring that the concept does not introduce unacceptable liability risks for actors and stakeholders.

Current liability risks identified during the concept development and activities (workshops):

1. Speed clearances/speed profile:

Airport becomes responsible for incidents if speed clearances are issued.

- Potential solution #1: Advise pilot's a point with a time constraint instead of issuing speed clearances / but the taxiing is no longer conflict free (could be a step towards ASTAIR concept implementation).

An issue in terms of human performance may arise from the above recommendation, as stated by the workshop participant: *"How often does the recommendation change? If you give information that the pilot needs to be somewhere at some point, you need to give a buffer of approximately 1 or 2 minutes.*

But then the calculation may not be anymore conflict free, so it needs to be recalculated. Eventually after e.g. 5 times recalculations, the pilot may not TRUST the system anymore." This in turn may have a negative impact on the pilot's workload.

- Potential solution #2: get the tug drivers to handle taxiing also while towing a/c (taxing would be managed by operators with a good knowledge of the ASTAIR platform, compared to pilots only 'visiting', and it would free some pilots' mental workload, for instance, during taxi for engine start up preparation, or during other pilot's checklist task).
- Another recommendation from a workshop participant was to use speed recommendations instead of hard speed constraints, and then it would be a pilot's responsibility to manage the recommended speed.

There may be a need for specific safety nets for autonomous taxiing vehicles surveillance to be discussed / gradual alerting system.

2. **Higher levels of automation:**

Higher levels of automation also raised questions about the confidence and trust with the AI and the ASTAIR system in general as this is expected to have a liability implication on the stakeholders. Several questions were raised regarding *"the view from the regulator and certification issues, or who is responsible in case of incident?"*. For instance, one participant stated the following during one of the workshops: "*The plan can be done by AI but the execution of the plan should remain with the human"*.

3. **Capacity increase**:

The following question was posed during the last workshop: *"Is the human capable of taking over at any point? You want automation to pack more traffic."* This is another crucial point which shall be investigated from the liability perspective due to potential risk that the human/ATCO may not be able to gain appropriate situational awareness if the AI system needs to be turned off (either due to malfunction or uncertainties on the human side). As with the automated system there is a potential to increase the traffic, this new level of traffic may not be suitable to be controlled by the human alone. Therefore, there may be a number of risks coming from this scenario, such as, as a first impact in this scenario would be the human/ATCO/pilot workload, situational awareness, and in turn safety. This will have a cascading effect on the Airports, ANSPs and regulators in order to understand the responsible stakeholder in case of an incident/accident.

This capacity increase risk shall be addressed also through the human-AI Collaboration, and Operational Feasibility validation objectives. This abnormal scenario shall be supported by operational procedures, specifically, "fallback to current mode of operations" procedures could be designed.

In summary, the following conclusion on the liability can be made:

- The plan can be done by the AI but the **responsibility** of the execution of the plan should remain with the human. This shall be clear to all stakeholders involved. The topic of human-AI collaboration is addressed through a Validation Objective (in ERP [10]) which will be validated through the validation exercise. The results on this objective will be reported in the Exploratory Research Report (ERR). This objective will explore other aspects, such as human performance and safety. Whereas a dedicated Liability Validation Objective will report on the Liability issues and potential mitigations. Both objectives will address the topic of **responsibility** (AI vs human).

- **Trust** in the system: the ATCOs shall be supported in their decision-making process, to ensure trust in the system. This could be addressed through the enhanced performance of the system, acceptable HMI, while supported by clearly defined procedures supporting ATCOs in their decision-making and during the collaboration with an AI, creating a seamless working environment and thus promoting acceptable teamwork. The trust area will be validated and reported also through a dedicated objective mentioned above (Human-AI Collaboration).
- **ASTAIR procedures:** Speed control procedures from the ATCO shall be validated with the use of ASTAIR, as currently a responsibility for taxiing (including the taxiing speed) lies with the pilot. If the pilots is provided with a speed allowance, then the responsibility shifts to the Ground Control. In current operations a controller can report to the pilot that the gate is taken, but do not normally issue a speed clearances to the pilot.

The liability topic may be supported by the following recommended activities:

- Application of the Legal Case methodology[5].
- Sharing and discussing results and recommendations.

In order to address any potential risks, the following preliminary success criteria were developed[i]:

- Identification of key new liability risks for all actors and stakeholders involved in defining, developing, and implementing the concept, according to the level of definition achieved at various validation stages.
- Identification of suitable measures in design, organisation, and policy to mitigate identified risks.
- Positive feedback from AB stakeholders on the proposed concept or suggestions for alternative enhancements.
- Ensuring that the concept does not introduce unacceptable liability risks for actors and stakeholders.

For the details on the Liability topic and the dedicated Liability Validation Objectives refer to ERP document [10].

[5] Legal Case methodology intends to support the integration of automated technologies into complex organisations, particularly in ATM. Its purpose is to address liability issues arising from the interaction between humans and automated tools, ensuring that these issues are clearly identified and dealt with at the right stage in the design, development, and deployment process. [9]

5 Conclusion

In this report, we described the results of our interviews, observation and workshops with stakeholders to better understand the current procedures, identify automation opportunities and gather important requirements for the project. We described several use cases including envisioned levels of automation associated and discuss the identified challenges on human automation teaming, path planning and liability.

Some of the results, including use cases raise different challenges for different airports. Even if it may appear specific, we believe that the use cases are generic enough to be used for other A-CDM airports.

These results will be used in future activities carried on in WP2 and WP3.

Impact on WP2

Depending on the complexity of the use cases in real life or the occurrence of high volume of instant changes in data and environmental conditions, the algorithms related to WP2 might show various behaviors in dealing with sudden changes. While adjusting the paths and plans of vehicles might be done relatively easily in case of TOBT changes of a few aircraft, or offering a remote holding solution could be easy in the event of the capacities of the remote holding locations are sufficient and the paths of other vehicles are not subject to change based on this solution, in complex situations where there is high traffic, too many delays or changes on aircraft TOBTs, limited capacity, the need to change the configuration of runways frequently might prevent the proposed algorithms from providing high quality or even feasible solutions. The entire system might require re-planning in highly complex scenarios. The practical challenges, especially the speed control which is mentioned to remain in responsibility of the pilot during the interviews, might also impact the solution quality of the proposed algorithms on WP2 since the solution quality is sensitive to the time and positions of aircraft and tugs at specific times. Other challenges are, although the queueing models related to decoupling operations were studied during AEON project using a high-level simulation independent of airport maps, they are not integrated within the path planning algorithms and as mentioned in the interviews when a small aircraft follows a large body aircraft while approaching a decoupling location it should slow down to keep a safety distance and this can also have an impact of outbound traffic and the solutions of the algorithms in WP2.

Algorithms performance to be usable in "real time" situations or find adequate task with temporal constraints. As mentioned above, algorithm performance and usability in real time depend on the complexity of the problem, such as how many aircraft are subject to TOBT change, whether defined constraints allow finding alternative feasible solutions without violating any of the constraints, are we in a time of the day where there is high traffic at the airport and the changes we need to make depends on many other parameters, how long before the action the algorithm must find a solution so that all operations can be arranged accordingly, the level of conflicts that need to be resolved. In the scenarios where TOBT values are changed only for a few of the aircraft, remote holding locations are easily accessible without requiring resolving conflicts with too many vehicles, when the number of vehicles the algorithm should plan the paths during replanning is not high, using AI in real time is expected to be feasible.

Impact on WP3

EUROPEAN PARTNERSHIP
Co-funded by the European Union

The proposed use cases involve different levels of automation including assistance to humans, human automation teaming and advanced automation.

While we identified several guidelines to design Human Automation teaming in level 1, 2A and 3A, there is unfortunately very few guidance on level 2B teaming. This is in our view one of the most challenging levels to design effective interaction given the possibly idiosyncratic approaches that users will develop to carry on their tasks efficiently. However, this is also, in our view, the one that could lead to better performances since the AI would benefit from human input to adjust to unexpected situations.

This approach will be explored in the design activities to support Human-Augmented AI approaches in which users input their expertise into the automated system to finely tune its actions and improve the overall performance.

Transitioning from several levels of automation will also force users to clearly assess their level of control and author automation when required. Given the number of aircraft to supervise and monitor, special attention will be given to reducing the cognitive workload and avoid long actions on the system. Hence gradual programming, i.e. authoring automation gradually could prove successful wand will be explored.

Another important aspect revealed by our workshops concerns the collaboration between several humans with the centralized AI system. For instance, parking managers, taxibots managers and ground supervisor will have to input data and make decision that will impact the systems constraints and ability to recompute new solutions. In addition to human-AI interaction, some use cases will require designing collaborative work between several humans to perform the tasks.

The proposed use cases and requirements will be considered in the evaluation plan. In particular, we will select the most relevant and identify evaluation strategies for our evaluation objectives. These elements will be described in Deliverable 5.1, the Exploratory Research Plan.

Impact on Validation (WP5):

Based on the initial liability risks (see Chapter 4.3), the following questions shall be addressed during the validation and reporting:

1. How far can we go with automation? Are the proposed levels of automation acceptable?
2. What is the view from the regulator? Could there be certification issues?
3. Is the human capable to take over at any point? Liability issue: in 3A who is responsible in case of incident? the AI developer?

EUROPEAN PARTNERSHIP
Co-funded by the European Union

6 References

[1] Bergé, P. 2005. Initial EMMA Air-Ground Operational Service and Environmental Description (OSED Initial), Document No. D1.
[2] EASA, A.I.R. 2. 0 2023. *A Human-centric Approach to AI in Aviation 2.0*. Technical Report, EASA.
[3] EUROCONTROL 2017. *Airport Collaborative Decision-Making (A-CDM) Implementation Manual*.
[4] EUROCONTROL Specification for Advanced-Surface Movement Guidance and Control System (A-SMGCS) Services.
[5] Eurocontrol Experimental Centre 2006. CONTROL TOWER OPERATIONS: ROLES DESCRIPTION - EEC Note No.
[6] ICAO 2001. Doc 4444 ATM/501 Air Traffic Management.
[7] ICAO 1984. Doc 9426-AN/924 Air Traffic Services Planning Manual.
[8] ICAO, A. and Volume, I. 2018. *Aerodrome Design and Operations, Annex 14 to the Convention on International Civil Aviation*. International Civil Aviation Organization.
[9] Contissa G. et al., Liability and automation: Issues and challenges for socio-technical systems, Journal of Aerospace Operations, vol. 2, no. 1-2, pp. 79-98, 2013.
[10] D5.1 ASTAIR DES HE SESAR ERP_v.00.00.02

EUROPEAN PARTNERSHIP
Co-funded by the European Union

7 List of acronyms

The following table reports the acronyms used in this deliverable.

Term	Definition
A-CDM	Airport Collaborative Decision Making
A/C	Aircraft
ADS-B	Automatic Dependent Surveillance–Broadcast
AEON	Advanced Engine Off Navigation
AI	Artificial Intelligence
AMS	Amsterdam Schiphol Airport
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASTAIR	Auto Steer Taxi at Airport
ATC	Air Traffic Controll
ATCO	Air Traffic Controller
ATM	Air Traffic Management
CDG	Paris-Charles de Gaulle Airport
CTOT	Computed Take Off Time
DES	Digital European Sky
EASA	European Aviation Safety Agency
ERP	Exploratory Research Plan
GH	Ground Handling
GSE	Ground Support Equipment
GND	Ground Controller
HCI	Human Computer Interaction
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
PDS	Pre-departure sequencing
NMOC	Network Manager Operations Centre
RMO	Runway Mode Operation
RTS	Real-Time Simulation
RWY	RunWay
SESAR	Single European Sky ATM Research

SESAR 3 JU	SESAR 3 Joint Undertaking
TOBT	Target Off Block Time
TSAT	Target Start Up Approval Time
TWR	Tower Controller
UC	Use Case

Table 1: list of acronyms

Co-funded by the European Union