JOINT UNDERTAKING

Concept outline

Deliverable ID:	**D1.4**
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:	**30 July 2025**
Edition:	**01.01**
Status:	**Official**
Classification:	**PU**

Abstract

The **ASTAIR (Auto-Steer Taxi at Airport) project** is a SESAR3 project aiming at improving the efficiency, safety, and predictability of ground operations at congested airports. The project focuses on automating taxi procedures through technologies like autonomous taxiing systems and tug vehicles and the required human automation teaming to perform safe and efficient airport operations. By integrating systems such as A-CDM (Airport Collaborative Decision Making) and A-SMGCS (Advanced Surface Movement Guidance and Control System), ASTAIR seeks to optimize traffic management, reduce delays, and enhance sustainability with green taxiing methods. The project also outlines future SESAR solutions and potential research directions, emphasizing the importance of routing and automation in improving airport operations.

This document provides a concept outline for the ASTAIR project, summarizing the operational scenarios, technological solutions, and expected outcomes.

Authoring & approval

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[2] Representatives of the beneficiaries involved in the project

Document history

Edition	Date	Status	Organisation author	Justification
00.01	02/06/25	Draft	ENAC	Creation
01.00	30/06/2025	Release	ENAC	Corrections after internal reviews
01.01	30/07/2025	Release	ENAC	Corrections after S3JU reviews

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ASTAIR

AUTO-STEER TAXI AT AIRPORT

ASTAIR

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

Table of contents

EUROPEAN PARTNERSHIP

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List of figures

EUROPEAN PARTNERSHIP
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List of tables

1 Executive summary

ASTAIR introduces automated taxiing to improve operational efficiency and reduce delays. It leverages the A-CDM (Airport Collaborative Decision Making) and A-SMGCS (Advanced Surface Movement Guidance and Control System) frameworks to create more predictable ground operations and alleviate operator workloads.

- Key Concepts:
    - Automated Taxiing: The project explores different automation levels, focusing on managing ground traffic at airports using technologies like tugs and autonomous taxiing vehicles.
    - Ecological Routing: By providing speed-regulated routes for vehicles, the project can reduce conflicts and improve predictability, safety, and efficiency.
- Benefits:
    - Operational Efficiency/Predictability: Automated systems reduce reactionary delays and support collaboration between ground operators, enhancing traffic flow and fuel consumption efficiency.
    - Safety: The system calculates safe, optimized routes for all ground vehicles, minimizing runway incursions and improving airport safety.
    - Human Performance: Operators workload is reduced by collaborating with the automated system that can handle routine tasks. Usage of radio communication is also significantly reduced; automated clearances being sent via datalink.
    - Sustainability: Green taxiing solutions, such as dispatch towing and electric taxi systems, are supported to limit the environmental impact of ground operations.
- Expected Outcomes: If successful, ASTAIR will significantly enhance safety, reduce fuel consumption, and optimize turnaround times, leading to smoother airport operations.

2 Introduction

2.1 Purpose of the document

This document describes the concept developed in the exploratory research project ASTAIR, targeting TRL 1 at the end of project. The objective is to describe how the concept impacts current operations with operational use cases, analyse its potential improvements to ground operations and its weaknesses or limitations that should be further researched.

2.2 Intended readership

The intended audience of this concept outline document includes:

- The key stakeholders targeted by the solution, in particular ground handlers, airport management, airlines, Air Traffic Control (ATC) operators and the industry providing taxiing solutions, most of which are also represented in the ASTAIR expert group
- The ASTAIR Consortium
- The SESAR 3 joint Undertaking (S3JU)
- The overall aviation community interested in the document, as it will be publicly available.

2.3 Background

ASTAIR project builds up on the results of previous SESAR exploratory research project AEON – Advanced Engine off Navigation (grant #892869). More specifically, both Air Traffic Management (ATM) and technological solutions proposed by AEON are enablers and complemented in ASTAIR, see 3.2.2.1.

Project Title	Project Description
SESAR EXPLORATORY RESEARCH PROJECT AEON - Advanced Engine Off Navigation (*completed*)	AEON defined a new concept of operations to make best use of green taxiing techniques; specifically, Taxibots, WheelTugs, e-Taxi, and single-engine taxiing were investigated to address airport ground operations at long to medium-planning and execution phases. ASTAIR is building on AEON Path planning algorithms.
SESAR CODA - Controller adaptative Digital Assistant	The CODA project aims at developing a system in which hybrid human-machine teams collaboratively perform tasks. ASTAIR and CODA do not share the same approach on Human Automation Teaming, especially in the use on neurophysiological measures, nevertheless some questions on delegation strategies may be addressed similarly.

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Project Title	Project Description
EVOLVE: Motion planning and control in the safety-critical situations (NWO Open Technology Programme, project 18484 (*completed*)	EVOLVE proposes to use an enhanced physics and data-based learning approach to the control of automated driving hazardous driving scenarios known as “edge cases” where representative data are statistically rare. The developed control algorithms will handle and guarantee safety during evasive manoeuvres for collision avoidance, something that current automated driving cannot guarantee. Motion planning and control models that were implemented in AEON and eventually in ASTAIR.
OWHEEL: Benchmarking of Wheel Corner Concepts Towards Optimal Comfort by Automated Driving (EU H2020-MSCA-RISE-2019 OWHEEL, project 872907)	The project OWHEEL aims at the development and evaluation of new concepts of automotive wheel corners as crucial elements of future vehicle architecture tailored to provide an optimal comfort during automated driving. The main goal of the OWHEEL project is to perform a deep analysis and provide on its basis the recommendations for future automated vehicle architecture.
SESAR 2020 exploratory research project Take Control (TaCO) (*completed*)	TaCo aims to define an automated system sufficiently powerful to both accomplish complex tasks involved in the management of surface movements in a complex airport and self-assess its own ability to deal with non-nominal conditions. TaCo allows Air Traffic Controllers to progressively create and tune automation with visual constructs that also assist them in understanding the behaviours, hence facilitating the handover if required. The concept of human automation teaming in ASTAIR project is developed upon the results of Take Control (TaCo)
SESAR TAM - Total Airport Management (PJ04 TAM, grant 733121) (*completed*)	TAM is interesting for ASTAIR development at several levels. First because centralization and automation of ground movement promoted in ASTAIR follows the same philosophy as PJ04 TAM, but also because PJ04 in the solution 29.3 investigated the usage of AI for routing. Routings and speeds profile for fuel optimized taxiing were calculated. The developed models proposed to the operational solutions and decision-makers decided whether the proposed solution will be applied. This corresponds to the level 1B (in reference to EASA level of automation). ASTAIR will go further into looking for conflict-free routing.

Project Title	Project Description
SESAR TRUSTY – TRUStworthy inTellingent sYstem for remote digital tower	The overall goal of TRUSTY is to provide adaptation in the level of transparency and explanation to enhance the trustworthiness of AI-powered decisions in the context of Remote digital towers (RDT). TRUSTY and ASTAIR will most probably share some problematics concerning human centric AI and human AI teaming, thus staying closely in touch will be fruitful for the project.

Table 1: Relevant results from previous projects that will be fed into the ASTAIR project

2.4 Structure of the document

In section 3, after setting the context of the project and the actual problem to solve, section 3.2.1 introduces the current operations in airports and the processes that should be impacted by the implementation of ASTAIR concept. The following sections 3.2.2, 3.2.2.1 and 3.2.2.2 present the ASTAIR concept, its enablers and stakeholders. In section 3.2.2.3, several use cases that have been defined during ASTAIR workshops are described to get more concrete details on the concept, some of them will be demonstrated in the final validation. Then section 3.2.3 addresses the limitations of the concept.

Section 4 presents a summary of the solution being developed in ASTAIR project and section 5 deals with the next steps to consolidate this initial concept.

Finally, section 6 lists all documents and other projects that are referred to in this document.

2.5 List of acronyms

Term	Definition
AC	Apron Controller
A/C	Aircraft
A-CDM	Airport Collaborative Decision Making
AEON	Advance Engine Off Navigation
AET	All Engine Taxi
AI	Artificial Intelligence
AIBT	Actual In-Block Time
AMAN	Arrival MANager
AO	Aircraft Operator
AOBT	Actual Off-Block Time

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APTO	Airport Operator
APU	Auxiliary Power Unit
A-SMGCS	Advance Surface Movement Guidance and Control System
ASTAIR	Auto-Steer Taxi at AIRport
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air traffic management
A-VDGS	Advanced-Visual Docking Guidance System
CATC	Conflicting ATC Clearances
CMAC	Conformance Monitoring Alerts for Controllers
CONOPS	CONcept of OPerations
CTOT	Computed Take Off Time
CWP	Controller Working Position
DES	Digital European Sky
EASA	European Union Aviation Safety Agency
ECI	Electronic Clearance Input
EOT	Engine Out Taxi
ERR	Exploratory research report
ETA	Estimated Time of Arrival
EXIT	Estimated Taxi In Time
EXOT	Estimated Taxi Out Time
FUM	Flight Update Message
GA	Grant agreement
GC	Ground Controller
GDPR	General data protection regulation
GH	Ground Handler

HE	Horizon Europe
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
ID	Identifier
LTO	Landing and Take-off
LVC	Low Visibility Conditions
LVP	Low Visibility Procedure
MTOW	Maximum Take-off Weight
NLG	Nose Landing Gear
OI	Operational Improvement
OTP	On Time Performance
PB	PushBack
PDS	Pre-Departure Sequence
PIC	Pilot in Command
RMCA	Runway Monitoring & Conflicting Alerting
RMO	Runway Mode of Operation
RTT	Round Trip Time
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
SET	Single Engine Taxi
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
STX	Sustainable Taxiing
TaCO	Take Control
TCL	Taxiway Centreline Lights
TFM	Tug Fleet Manager

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TIPO	Taxi In Push Out
TNA	Training Need Analysis
TOBT	Target Off-Block Time
TRL	Technology readiness level
TSAT	Target Start-up Approval Time
TT	Turnround Time
TTOT	Target Take-off Time
Tug / Taxibot	Taxibots are tugs certified for dispatch towing of aircraft with passengers on board. Both terms (tug and taxibot) are used in the document.
VIP	Very Important Person
VTT	Variable Taxi Time

Table 2: list of acronyms

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3 Concept outline

3.1 Problem statement

In 2023, the average departure delay per flight in Europe was 17.8 minutes, nearly unchanged from 2022. Meanwhile, the average arrival delay increased slightly by 0.2 minutes to 16.2 minutes. This smaller arrival delay suggests that airlines were able to mitigate some of the departure delays during the flight. Additionally, reactionary delays contributed an extra 8.2 minutes to each flight, with the highest incidences typically occurring in the afternoon and evening.

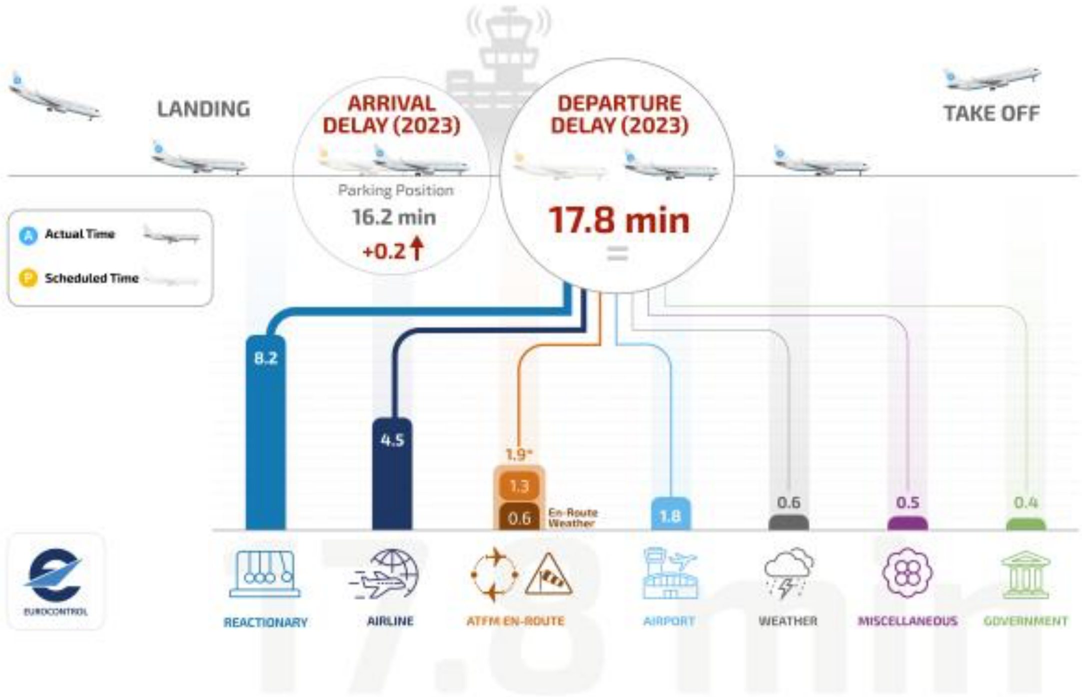

Figure 1 : 44th EUROCONTROL Data Snapshot delves into the causes of flight delays.

Keeping delays as low as possible on ground operations would reduce the risk of a snowball effect of reactionary delays throughout the rest of the operational day. In addition, all trajectories' computations for in flight optimisation are relying on flight schedules, any delays would lower the gains and force live re-computations.

Implementing automated taxi phases would improve the predictability of take-off times and enhance the anticipation of flight update messages (FUMs). Currently, taxi speeds are not managed by Air Traffic Control (ATC), resulting in variability influenced by numerous factors such as the time of day, airline policies, pilot familiarity with the airport, and readiness of pilot checklists. By introducing speed clearances, we could reduce this variability, thereby enhancing safety.

Increasing the level of automation in ground operations would also alleviate the workload on operators, allowing them to focus on supervision and risk anticipation by automating tedious and repetitive tasks. This would streamline traffic flow and lead to reduced fuel consumption, contributing to more sustainable operations overall. In addition, improving collaboration between ground operators, as demonstrated in AEON results, would also foster greener ground operations.

3.2 Concept description and operational scenarios

3.2.1 Current operational and technical context

Aircraft ground operation for taxi refers to the procedures and activities involved in moving an aircraft on the ground from one location to another, typically between the parking area and the runway. International Civil Aviation Organisation (ICAO) describes taxiing as the movement of an aircraft on the surface of an aerodrome under its own power, excluding take-off and landing [15]. Several additional processes may be required to enable efficient taxi operations, specifically at high-capacity airports. These processes include planning and preparation processes before the actual taxi operation -as defined by ICAO- can start.

During the landing and take-off (LTO) cycle, aircraft usually spend most of the time on the ground, as they must manoeuvre different aerodrome layouts to take off or land. Conventional departure procedures include pushback (with engines off) from the parking stand and taxi (with engines on) till they lift off from the runway, while the arrivals follow an engine-on schedule till the parking stand.

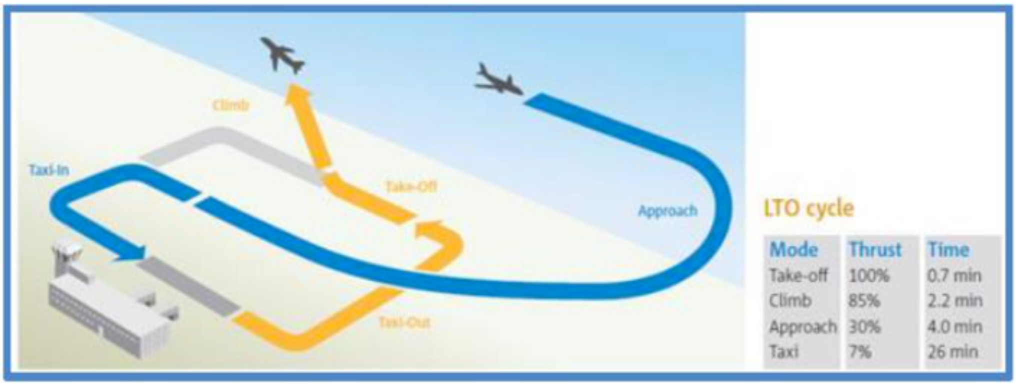

Figure 2: Landing & Take-off (LTO) Cycle

Efficient management of aircraft taxi operations is essential for ensuring smooth airport operations, minimizing delays, and enhancing overall safety. In the context of Airport Collaborative Decision Making (A-CDM), which is a collaborative approach aimed at improving the overall efficiency of airport operations, taxiing plays a significant role as it influences airport surface efficiency, runway throughput, and overall traffic flow.

A-CDM is a concept that promotes collaboration among airport stakeholders, including airlines, ATC, ground handlers, and airport operators (APTO). The primary goal of A-CDM is to enhance predictability and reliability in airport operations by sharing real-time information and coordinating activities more effectively.

In addition to the importance of collaboration in improving efficiency, effective communication and coordination are crucial during this phase to ensure the safe and efficient movement of aircraft on the airport surface. Advanced Surface Movement Guidance and Control Systems (A-SMGCS) plays a pivotal role in enhancing the safety and efficiency of aircraft taxi operations. A-SMGCS is a system specifically designed to enhance situational awareness for both ATCOs and pilots during aircraft movements on the ground. It integrates surveillance, routing, guidance, and control capabilities to improve the overall safety and efficiency of surface operations at airports. By offering real-time information about the positions of aircraft, vehicles, and other obstacles on the airport surface, A-SMGCS aids in preventing runway incursions and reducing delays caused by ground congestion.

SESAR provides a solution called Extended Airport Safety Nets for Controllers at A-SMGCS Airports (Solution PJ.02-W2-21.1) in order to improve safety for "High Performing Airport Operations" as Support Tools for controllers at A-SMGCS Airports to detect potential and actual conflicting situations, incursions and non-conformance to procedures or ATC clearances, involving mobiles (and stationary traffic) on runways, taxiways and in the apron/stand/gate area as well as unidentified/unauthorized traffic.

This solution updates and extends the Airport Safety Nets Conflicting ATC Clearances (CATC) and Conformance Monitoring Alerts for Controllers (CMAC) to cover the entire airport surface. It also improves the timing of CATC alerts for runway operations by predicting if an incident will occur due to conflicting clearances. This reduces possible nuisance alerts. Other new alerts are Runway Monitoring & Conflicting Alerting (RMCA) or CMAC vs clearance and Take Off vs Take Off (Converging Standard Instrument Departures (SIDs)). [14]

In this document, A-CDM and ASMGCS are described because ASTAIR concept targets large airports with high congestion levels or long average taxi times, implementing A-CDM and A-SMGCS. Details on A-CDM and A-SMGCS in relation to the taxi phase will be explained in section 3.2.1.1.

Considering the above, ASTAIR project offers improvement of services in ground operations that are fully automated in predicting, guiding, forecasting speed profile and ensuring safety by calculating the possibility of conflicts occurring, that will move from all human orders to Human-Automation-Teaming orders.

3.2.1.1 Current Taxi Operations Method

Taxi procedure can commence after ATCO/Ground Controller receives Flight Plan of departing aircraft or traffic information pertaining to arriving aircraft and the Flight Crew receives the Target Off-Block Time (TOBT) to initiate the request for pushback clearance. TOBT is defined as the time when the aircraft is estimated to be ready for pushback (PB) with doors closed, all ground equipment disconnected and the PB truck loaded. Upon receiving information, ATCO/Ground Controller can determine the sequence for take-offs while also managing the arriving aircraft proceeding to their designated parking stands. This sequence must take into account the traffic situation and conditions at that time. Sometimes, the sequence can change depending on safety priorities or other conditions (such as emergency and VIP passengers).

Departing aircraft can start the movement by requesting Pushback or Start-up clearance to the Ground Controller. Pushback clearance is granted to an aircraft when it is ready to move from its parking position to a position on the taxiway where it can begin its movement toward the runway (taxi-out). This process is typically performed by a tug vehicle that pushes or pulls the aircraft out of its gate. Start-up clearance is provided when an aircraft is cleared to start its engines and taxi on the airport surface.

Taxiing requires that taxi clearance is obtained prior to the manoeuvre. Taxi clearances contain concise instructions and adequate information to assist the flight crew to follow the correct taxi routes, avoid collision with other aircraft or objects and minimize the potential for the inadvertent entry on an active runway. When a taxi clearance contains a taxi limit beyond a runway, it must contain an explicit clearance to cross or an instruction to hold short of that runway [15].

Currently, ground operating methods keeping the main engines-on or using single-engine techniques to taxi aircraft from gate to runway or vice versa. In this case, All Engine Taxi (AET) is normally adopted during both Taxi-Out and Taxi-In phases of aircraft ground operations. Another taxi method is known as Single Engine Taxi (SET), where only one engine is used during taxi. In SET operations, both the departure and arrival procedures follow a sequence of activities like AET operations. The Pilot in Command (PIC) decides when to switch on or off the second engine(s) for warm-up/cooling down process, before take-off or after landing. The SET method is usually used by airline during the Estimated Taxi-In Time (EXIT) phase more than the Estimated Taxi-out Time (EXOT) phase, to save fuel during longer taxiing times at the airports. Moreover, in the EXOT phase the pilot will eventually have to start both engines to prepare for take-off. EXIT includes runway occupancy and ground movement time, whereas EXOT includes pushback and start-up time, ground movement, remote or apron de-icing, and runway holding times.

To optimize the Round-Trip Time (RTT) effectively, the Airline Operator/Flight Crew and Ground Staff must consider three primary variables. These variables include the EXIT and EXOT parameters (commonly also called Variable Taxi Times (VTT)), and the Turnaround Time (TT). The Turnaround Time represents the duration during which the aircraft is stationed between the Actual In-Block Time (AIBT) and Actual Off-Block Time (AOBT). To be clear, there exists a discrepancy in how different stakeholders within the aviation industry define Off-Block moment. While airlines typically refer to the Off-Block moment as “Parking Brake Release,” airports have their definition as “First aircraft move under pushback,” and ground handlers describe it as “Aircraft cleared for the beginning of pushback” [9].

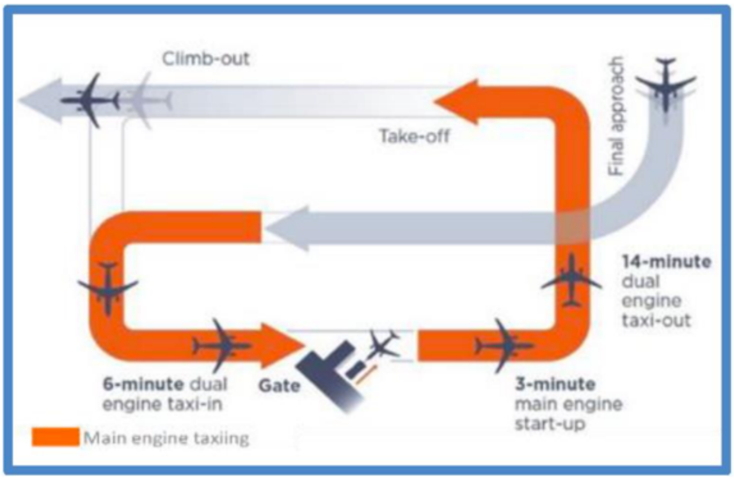

Figure 3: Main Engine-on footprint during LTO (time indicative)

3.2.1.1.1 Pushback (PB)

Pushback means the movement of an aircraft from a nose-in parking stand using the power of a specialised ground vehicle (pushback truck or tug or tractor) normally attached to or supporting the nose landing gear. It is commonly the second part of a Taxi in Push Out (TIPO) procedure at airport terminal gates and will be necessary to depart from all except self-manoeuvring (open) parking stands unless the aircraft type is capable of power-back and local procedures allow this [7].

Power-back procedures have been used in the past but have become obsolete at most airports due to risks involved (jet blast) and therefore will not be considered as standard practice.

From a gate

The most common method is a pushback truck using a towbar to connect with the aircraft (load). Another typical method uses a 'towbarless pushback truck' equipped with a mechanism to lift the nosewheel of the aircraft. Once the PIC has given their confirmation of 'brakes released' to the person in charge of the ground crew who are to carry out the pushback, the ground crew become temporarily responsible for the safe manoeuvring of the aircraft in accordance with either promulgated standard procedures or as specifically agreed beforehand.

The ground crew then pushes back the aircraft from the aircraft stand as per procedures and instructions. Once in safe position (at/near end of the pushback procedure), the main engine(s) will be started one by one. SET operations may have a positive impact on pushback since it will take less time to start one engine instead of multiple.

Thereafter the pushback truck will disengage (unload), and the bypass pin removed from the aircraft nose gear (if applicable) by the ground handling staff. The pushback truck will relocate to a pre-defined safe location, and the ground handling crew will give the 'thumbs up' signal to the pilot in command (showing the bypass pin if applicable) to indicate the pushback procedure has been completed and pushback vehicle and ground crew are in a safe position. The PIC becomes then responsible again for the safe manoeuvring of the aircraft.[9]

From an open (remote) aircraft stand

When the aircraft is parked at an open stand (Taxi-in, Taxi-out parking), a pushback truck may not be necessary if the aircraft can leave the stand on its own power, and if it is safe to do so (e.g. low risk of jet blast). For safety reasons, a pushback with a tug from an open stand is still normal operations in most cases.

However, in ideal and common open/remote stand layout, the aircraft taxies at the assigned parking stand on its own. Since no pushback truck is required, the departure process from a remote stand is simpler, as pushback and disengage (unload) pushback truck steps can be removed from the process.

At some open stands (mainly where there are jet blast issues), the engines cannot be started on the stand, but the aircraft needs to be pushed back or towed to a safe startup location first. In those cases, the pushback phase(s) needs to be added, similar to a departure from a gate.[9]

3.2.1.1.2 Aircraft Towing

Aircraft towing is the forward movement of an aircraft, usually with engines off, using the power of a specialised ground vehicle attached to or supporting the nose landing gear. Towing can be used for the movement of both in service and out of service aircraft (in most cases move to/from another aircraft stand or to/from a maintenance facility).

Towing is not considered to be part of taxi operations (since the aircraft engines are switched off and the aircraft does not move under its own power). This activity should not be confused with pushback procedure, where the aircraft initially moves backward by means of a pushback truck.

Pushback procedures may contain a combined backward and some forward movement (with the same vehicle still attached to the aircraft) also known as ‘Push-Pull’ procedure. This typically short forward movement is part of the pushback procedure. [9]

3.2.1.1.3 Taxi Out

Taxi-out is the process phase from the moment the pushback procedure starts when aircraft is parked at a connected gate (or starts moving forward under its own power when leaving from an open aircraft stand and no pushback procedure is necessary) until (and including) it reaches the departure runway holding/intersection for take-off. In the A-CDM context, the taxi-out time is referred to as EXOT (Estimated Taxi-Out Time).

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Figure 4: EXOT Calculation Methodology

Upon receipt of the taxi clearance from ATCO/ground controller, and the ‘thumbs up’ signal by the ground handling staff at the end of the pushback procedure, the PIC can start taxiing (using the engines) towards the departure runway (or intermediate holding point/de-icing pad as applicable). **The choice of speed to taxi through taxiways depends largely on airline internal policies, pilot situation awareness, taxiway surface conditions and airport speed limitations.**

It is not uncommon that aircraft taxi at a relatively high speed to reduce ground time or trying to stay within the Calculated Take-Off Time (CTOT) deadline. Taxi out time cannot be less than the time needed to warmup the engines.

Some airports have taxi speed limitations for safety/environmental reasons, but this is not very common yet. Normally, the routings of the departing aircraft are carefully planned in a way to avoid intersection conflicts, jet blasts or any other safety concerns and aid in reaching the desired departure runway holding/intersection with the least delay. The PIC should have the situational awareness of the airport they are operating both under normal and non-normal/Low Visibility Conditions (LVC).

The actual taxi route may be amended as necessary. The initiative is typically with the ATCO, but the PIC may also do a taxi route change request if there is a reason to do.[9]

3.2.1.1.4 Push and Hold

In some cases, such as the delay of an aircraft departure, the term Push and Hold (Remote Holding Procedure) is known. Push and Hold is a procedure adopted by some aircraft operators for use when air traffic control (ATC) have advised of an expected significant delay for take-off to allow their flights to record an on-time departure and/or to clear a gate for re-use. If the APTO directly controls gate occupation, then the procedure may also be used by them for gate-release purposes. It involves an aircraft ground-positioning, usually under its own power, to what are often specially designated remote parking stands. Here, the engines are shut down and aircraft services are maintained by the use of the Auxiliary Power Unit (APU) until engine re-start is authorised by ATC. [10]

The purpose of push and hold is to enable approved airline operators to request remote holding for an aircraft to release its stand for re-use, to release pushback crews and contribute to the On Time Performance (OTP). An aircraft that has been issued a CTOT, which results in more than 30 minutes between its Target Off-Block Time (TOBT) and Target Start Up Approval Time (TSAT), is eligible for a push and hold.

ATCO selects this procedure at their discretion based on the departing runway and considering the operational performance on the day. Push and Hold is not permitted during Low Visibility Procedures (LVPs) for safety reasons.[11]

3.2.1.1.5 Taxi In

Taxi-in is the process phase starting from the moment the aircraft is leaving the arrival runway after landing to the aircraft parking stand (open stand or connected gate) as shown in the Figure 5. In the A-CDM context, the taxi-in time is referred to as Estimated Taxi-In Time (EXIT).

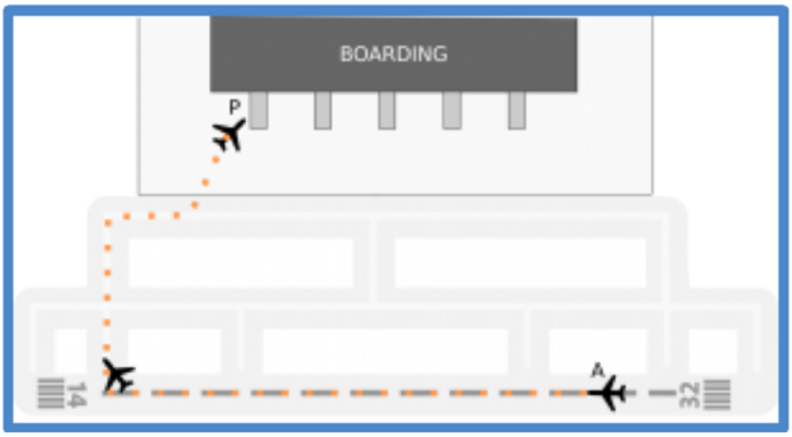

Figure 5: EXIT Calculation Methodology

Unlike the Pushback and Taxi-out, the Taxi-in after landing to a parking stand (either a connected gate or at an open aircraft stand) is typically a straightforward process that does not require assistance from external ground service tugs. The aircraft uses the aircraft engine(s) power until it comes to a full stop at the connected gate or open aircraft stand. The Taxi-in time is generally shorter than Taxi- out time but this also depends on the runway exit that will be taken and its distance to the aircraft stand. The runway exit can be requested by ATCO, depending on factors such as wind condition, traffic density, shortest taxi-routes to the gate, etc. However, the PIC will decide the safe runway exit to take, taking into account occupying the runway as short as possible for other traffic.

It typically takes 3 minutes before aircraft engines can be shut down (‘engine cooldown’). The conventional taxi-in usually allows for the engine cooldown to take place. [9]

3.2.1.2 Airport Collaborative Decision Making (A-CDM)

A-CDM [12] is the concept which aims at improving Air Traffic Flow and Capacity Management (ATFCM) at airports by reducing delays, improving the predictability of events and optimising the utilisation of resources.

Implementation of A-CDM allows each A-CDM Partner to optimise their decisions in collaboration with other A-CDM Partners, knowing their preferences and constraints and the actual and predicted situation.

In implementing the A-CDM concept, several partners play a crucial role in contributing to its success. Some of the key partners involved in the implementation of A-CDM include APTO, Ground Handler, Aircraft Operators, Network Operations, Air Traffic Control, and other Service Providers (such as De-icing Companies, MET Office, Fire Fighting, Police, etc).

The decision making by the A-CDM Partners is facilitated by the sharing of accurate and timely information and by adapted procedures, mechanisms and tools. The A-CDM consists of several elements, including Information Sharing, Milestone Approach, VTT, PDS, Adverse Condition and Collaborative Management of Flight Update.

To keep the overview and share the updates, the airport uses A-CDM platform (dashboard). Airport communities also utilize applications for mobile devices to share A-CDM milestones and other relevant information to facilitating a common view and can help in the coordination.

3.2.1.3 Advanced-Surface Movement Guidance and Control System (A-SMGCS)

An A-SMGCS [13] is a system that supports surface movement operations in all weather conditions at an aerodrome based on defined operational procedures. The implementation of an A-SMGCS and its various services and functions is a local decision based on the needs of an aerodrome and any European, national or regional mandates. The services include:

The Surveillance Service

This service provides the position, identification and tracking of mobiles and can include a combination of the following services. This service is the first and minimum service that must be implemented and is a key enabler for all the other services. The service provides situational awareness of aerodrome traffic through the identification, position and tracking of aircraft and vehicles within a predefined coverage volume. For the positive identification of targets at least one cooperative sensor is necessary. To detect any mobile, in particular intruders or aircraft with an inoperable transponder, at least one non-cooperative sensor is needed.

The Surveillance Service provides a synthetic representation of the aerodrome traffic situation based on Aerodrome Environment, position of all cooperative and non-cooperative mobiles and obstacles on the movement area, and identity of all cooperative mobiles on the movement area.

The Airport Safety Support Service

This service provides an automated alerting service to Controllers (ATCO). It detects and triggers at least one of the following types of alerts such as Runway Monitoring and Conflict Alerting (RMCA), Conflicting 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.

Based on the experience and practices of current A-SMGCS in operation in Europe, two stages of alert have been defined as Stage 1 alert (an INFORMATION alert) and Stage 2 alert (an ALARM alert). Stage 1 alert is used to inform the ATCO of a potential hazardous situation. According to the situation, the ATCO receiving a Stage 1 alert may take a specific action to resolve the situation. On the other hand, Stage 2 alert is used to inform the ATCO that a critical situation is developing requiring immediate action.

In the context of type of alert situation, the RMCA is a short-term conflict alerting tool that monitors movements on or near the runway and detects conflicts between an aircraft and another mobile.

CATC provides an alert when the ATCO inputs an electronic Clearance via the Human Machine Interface (HMI), that according to a set of locally agreed rules is not permitted from an operational and safety point of view when compared to any other previously input electronic Clearance. The detection of CATC provides an early prediction of a situation that, if not corrected, would end up in a hazardous situation. The CATC alerts for the Ground Controller require the implementation of the Routing Service to predict the trajectories when aircraft are pushing back from their stands or are taxiing. The HMI can be adapted to give a predictive indication to the ATCO that if a specific Clearance is input, it triggers a CATC alert. This helps the ATCO's situational awareness and normally prevents an incident due to a wrong Clearance being issued.

The last type of alert situation is CMAC. It provides ATCO with appropriate alerts when the A-SMGCS detects the non-conformance to procedures or Clearances of mobiles on runways, taxiways and in the apron/stand area. The integration of Electronic Clearance Input (ECI) with information such as flight plan, surveillance, routing, published rules and procedures allows the system to detect inconsistencies and alerts the ATCO. The main benefit of this is the early detection of ATCO, Flight Crew / Vehicle Driver errors that, if not detected and resolved, might result in a hazardous situation.

The Routing Service

This service generates ground trajectories for mobiles. In most cases, these trajectories for aircraft head towards the assigned runway holding point or parking stand, or for vehicles, to positions on the movement area. Routes can be created or modified by the ATCO 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.

Explanation about the recommended status of routes to be presented to ATCO are defined as follows:

- Planned route: Before the mobile starts moving on the surface, or in the case of an arriving flight before landing, the system generates a route based on the operational situation (runways and taxiways in use) and flight data provided by the Mobile Information Database. Any change of constraint such as a runway change or taxiway closure is automatically taken into account by the Routing Service and the planned route is updated without ATCO interaction
- Cleared route: When the ATCO clears the mobile to start moving on the surface, the route status changes to ‘cleared’ up to the Clearance limit and the route is the same as the planned route unless the ATCO has modified it. When the Routing Service is implemented with the CMAC function, any change of constraint that affects the cleared route such as a runway or taxiway closure generates an alert to the ATCO normally requiring them to modify the cleared route.
- Pending Route – Following a Clearance (e.g. Taxi), the pending route is any portion of the planned route that has not yet been cleared.

Due to operational events or changes, a Controller must be able to either modify an existing route or create a new route. Route modification is a modification to a generated route can either happen before the corresponding mobile has begun to move (e.g. planned route), or after the mobile starts moving (e.g. revision of a cleared/pending route).

The Guidance Service

This 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 Controller Working Position (CWP) is made available to provide Controllers with an HMI and for some services an ECI means.

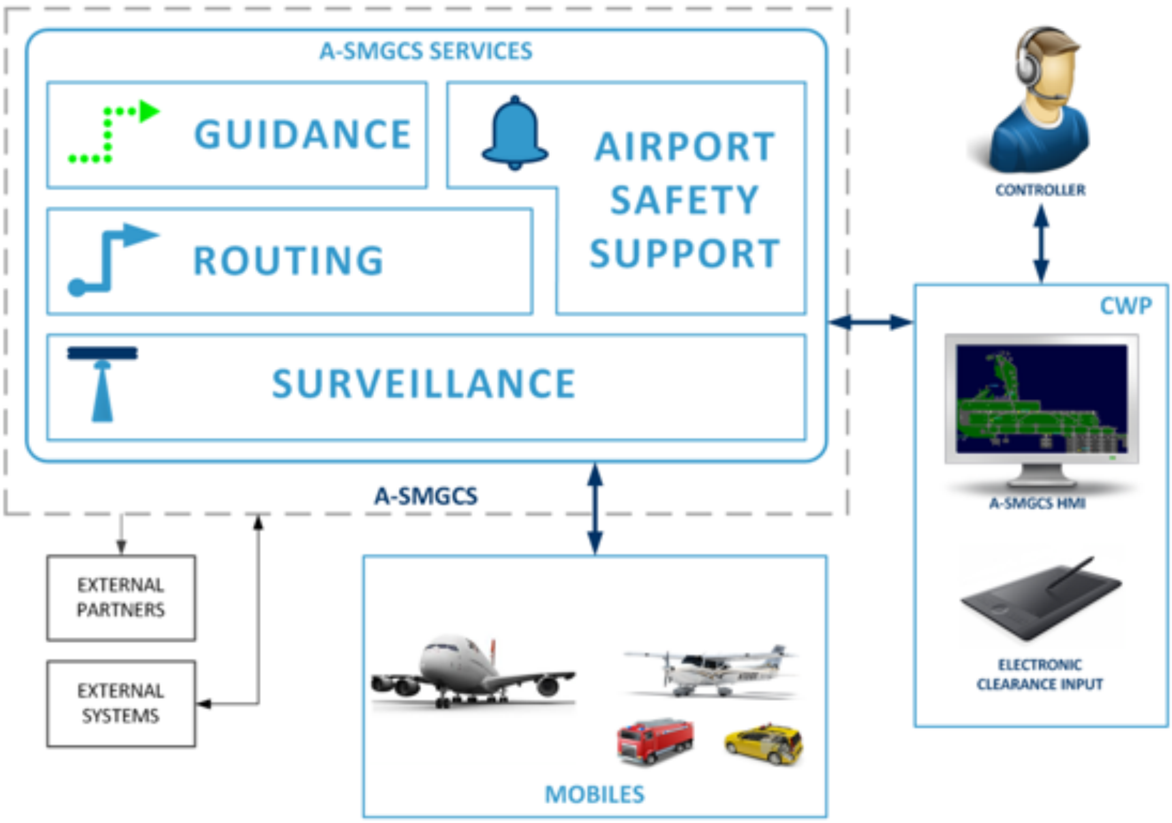

Figure 5: A-SMGCS Overview

Various actors are involved in the A-SMGCS environment. The business domain and objectives of each actor determine their level of participation/involvement. The main business organisations in relation to the A-SMGCS environment are:

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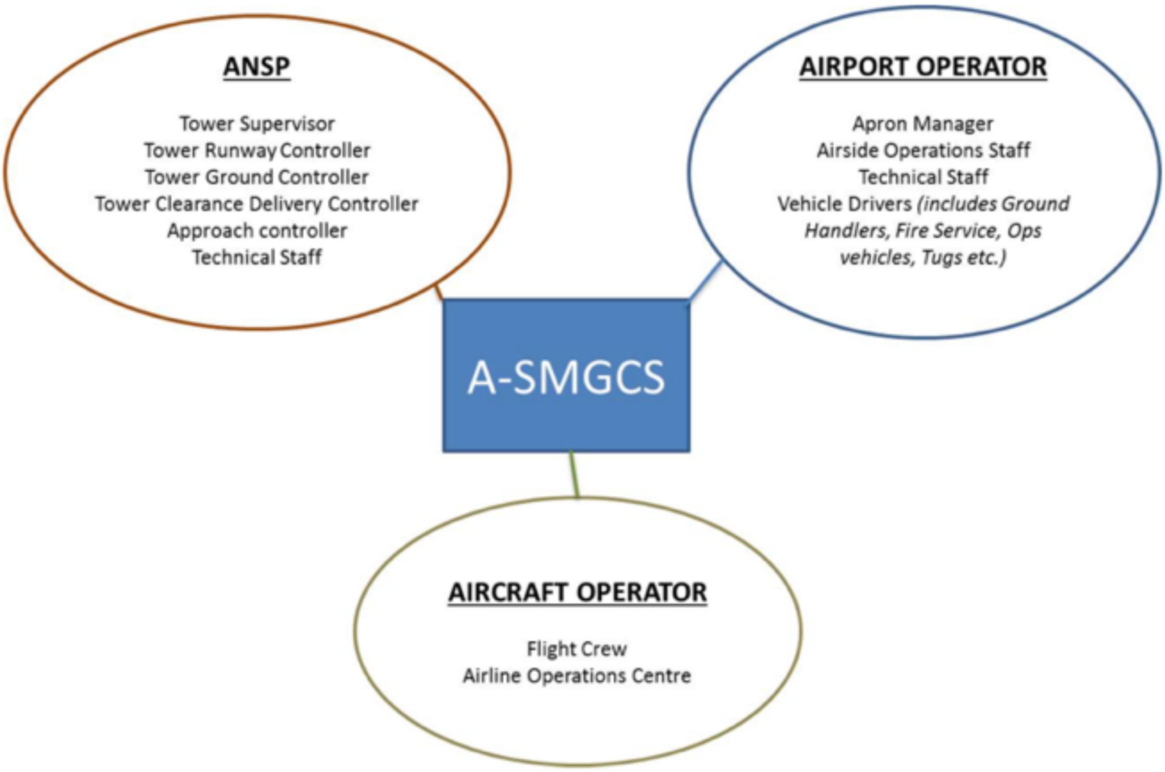

Figure 6: A-SMGCS Business Organisations

3.2.1.4 Sustainable Taxi Operation Solutions

In this chapter, the concept of Sustainable Taxi Operation Solutions [9] available today or anticipated within the short-medium term (approximately 5 years) will be explained. These solutions can be applied in the different phases of the taxi process and can be procedural (e.g. Single Engine Taxiing), technical (using onboard or on-ground technologies) or a combination of those. These taxiing techniques have an impact on the sequence of activities during taxi phase.

3.2.1.4.1 Single-Engine Taxi (SET) Technique

SET refers to the utilization of only one aircraft engine for taxi operations, as opposed to using all engines, which is known as AET. Alternatively, Engine Out Taxi (EOT) is employed by airlines to indicate taxi with three running engines on a four-engine jet aircraft. In this document will use SET denote taxiing with less than all engines operational.

Aircraft Operators (airlines) implement company-specific policies regarding the use AET and/or SET, depending on aircraft types and specific operations. In some airports, SET is promoted as standard operating procedure. At some airports, SET is prohibited when crossing live runways for reasons of potential runway obstruction in case of engine failure whilst crossing, assumed higher risk of jet blast etc.

In SET, both the departure and arrival procedures follow a similar sequence of activities to the current operations at the airport, except for the fact the aircraft is operated using single engine-on. The PIC gets to decide when to switch on or off the other engine(s) for respectively warm-up/cool-down processes, prior to take-off or after landing. The decision to switch on or off the engines also depend on the airline policies. These are generally decided keeping in mind the safety aspects of aircraft, ground crew and, also, from a maintenance standpoint

Various factors such as the complexity of the airport taxi-out route, aircraft weight, workload, pre-departure procedures, engine warm-up times, and weather conditions influence the crew's decision to choose between AET or SET.

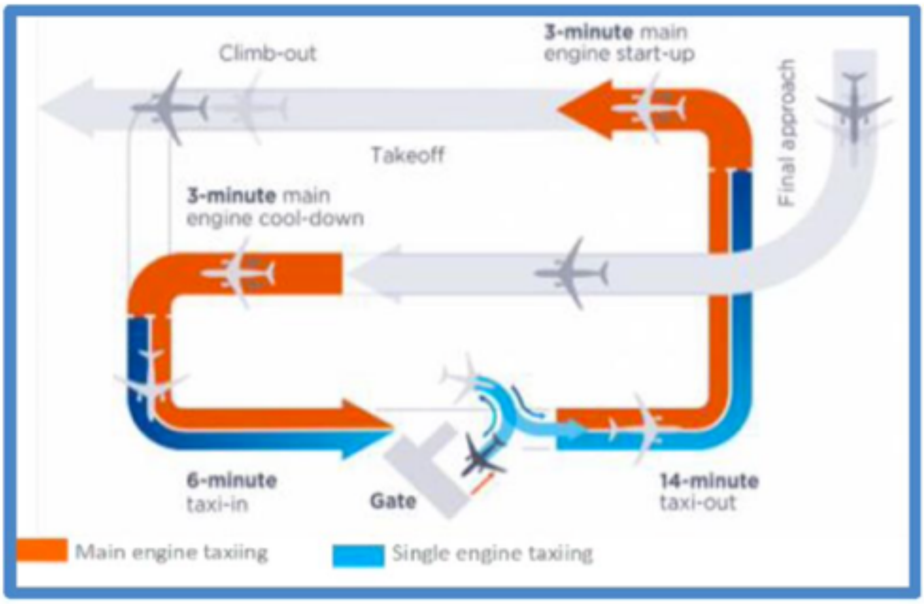

Figure 7: Single Engine-off footprint during LTO

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3.2.1.4.2 On Board Solution

Figure 8: An onboard technology taxi system (electric green taxi system - EGTS) as presented during Paris Air Show 2013

An on-board taxi solution or in the **AEON CONOPS** document known as **Autonomous Taxiing Operation (E-Taxi)** is an electric taxi system embedded in the nose or main landing gear. It enables pilot-controlled forward and reverse movement in gate and terminal areas and during taxi operations without tractors or jet engines, which may in some solutions add to increased manoeuvrability of aircraft at the apron, for example the on-board systems can be used for towing as well if the local conditions permit that and the aircraft is operated by a qualified operator.

These technologies could also come with optional camera/sensor systems that will provide pilots with improved situational awareness for all manoeuvres. It reduces engine usage during ground movement except during engine start-up, warm-up, and taxi onto the runway. While taxiing, the aircraft APU supplies power to the aircraft electrical, hydraulic and air conditioning systems.

The on-board solution can offer some advantage in turnaround time because no external vehicle is needed, and the load/unload sequence can be eliminated from the process steps. In addition, very tight manoeuvres are known to be feasible because the full turn radius of the nosewheel can be used.

On-board taxi solution systems can reach speeds ranging between 9 to 20 knots on the ground. Some on-board taxi solutions, particularly those installed in the nose landing gear, may operate in a hybrid mode (i.e., with one engine started) to gain speed during taxiing when their speed is reduced.

Figure 9: An onboard technology taxi system (Wheel Tug)

The lack of engine intake or engine blast risks has a positive impact on the risk level and enhances risk mitigation in the vicinity of aircraft stands, which also applies to on-ground solutions (see 3.2.1.4.3). Therefore, all factors should be weighted in to make an impact assessment and balance pros and cons, as with any system or procedure.

Pushback and Taxi Out

The main difference seen on ground operation is the shift of responsibility for wheelback (instead of pushback) from the GH staff to the Flight Crew, during normal operations. In **AEON CONOPS** document the term "**wheelback**" refers to an aircraft using its on-board taxi solution system to move in reverse, as opposed to "pushback", referring to either a legacy tug with a towbar or towbar-less tractor.

The pilot controls the on-board taxi solution in the same way as normal taxi operations, steering via tiller and nose gear and braking via the aircraft brakes till the aircraft reaches the designated cut-off point. Considering the airside operational constraints, the aircraft operating manual and the airline policies, the Flight Crew can decide to start the engines during the taxiing phase of the aircraft, taking into consideration factors such as the engine warm-up time.

Taxi in

On arrival, the aircraft can operate the on-board taxi solution (e-taxi) mode or by means of the hybrid mode, where the on-board taxi solution system is activated, and one engine will remain in idle mode to support breakaway in stop-and-go situations. As with taxi-out, the flight crew have the option to operate the aircraft either in on-board taxi solution or hybrid mode if allowed by company policy and/or local regulations.

It is worth noting that the onboard system allows fine-tuning of aircraft's position at the stand, which can be particularly beneficial when the aircraft missed the final position and cannot retrack without the assistance of a tug.

The Figure 10 shows the sustainable LTO operations with main engines only operating in the last part of taxi-out and first part of taxi-in. However, when more propulsion energy is needed, a hybrid mode (Figure 11) is possible where the on-board taxi solution systems is supported by SET. The single engine off phase can be operated for about 10-11 min out of the total 14 min of EXOT time and about 3-4 min are utilised for second engine-start up procedure. Similar process can be followed during the EXIT phase, wherein single engine off and cooling down operating cycle is used in the hybrid mode option, till the a/c reaches the gate /parking stand.

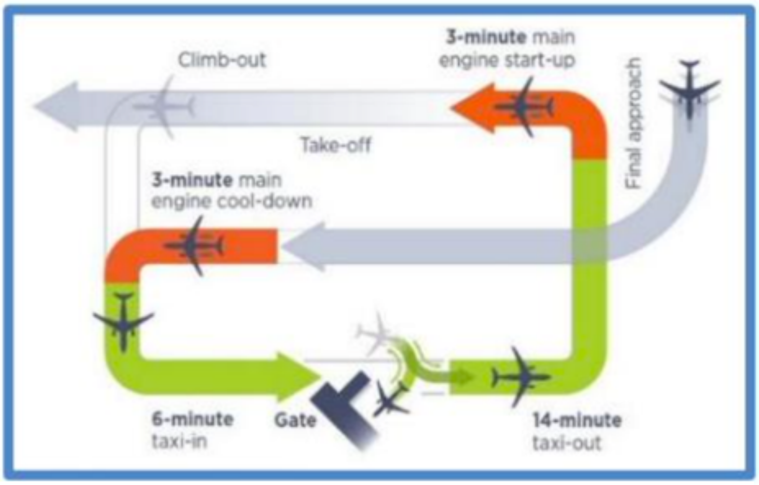

Figure 10: LTO cycles for sustainable (e-taxi install on the main landing gear)

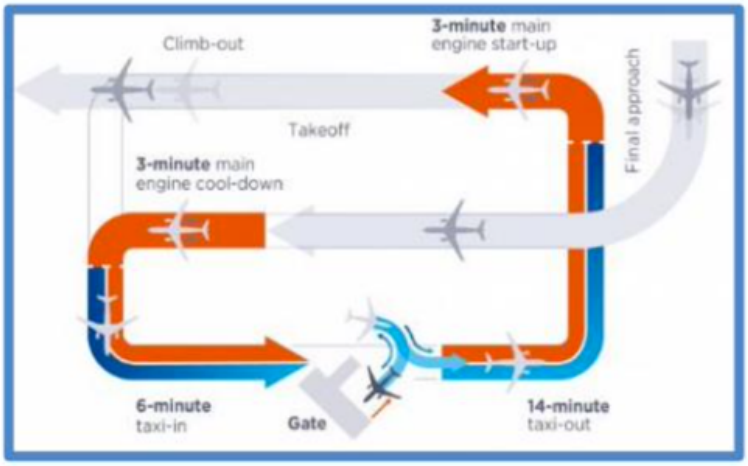

Figure 11: LTO cycles for hybrid operation (SET/on-board taxi solution (e-taxi))

3.2.1.4.3 On Ground Solution

On ground solution or in **AEON CONOPS** document known as **Non-Autonomous** taxi operation, is simply put, a towing vehicle that allows aircraft to taxi for departure to the runway entry/holding point without the use of the main engines. It may also be used for arrival aircraft with some procedure change after the aircraft has vacated the runway. The system is designed to tow aircraft safely, efficiently and without causing fatigue damage to the nose landing gear and does not have speed or distance limitations of normal tow trucks.

This solution is aimed to facilitate the sustainable taxi-out and taxi-in of aircraft by utilizing a specialized vehicle instead of the aircraft's own engines. By allowing a convoy (equipment and aircraft attached to one another) to taxi using the drivetrain of the Sustainable Taxi Vehicle, the aircraft's own engines become superfluous. The use of the Sustainable Taxi Vehicle allows the pilot in control of the aircraft to take control of the convoy during the main taxiing phase (after loading and/or pushback) using the aircraft's own steering and braking systems, thereby minimising forces applied to the aircraft structure.

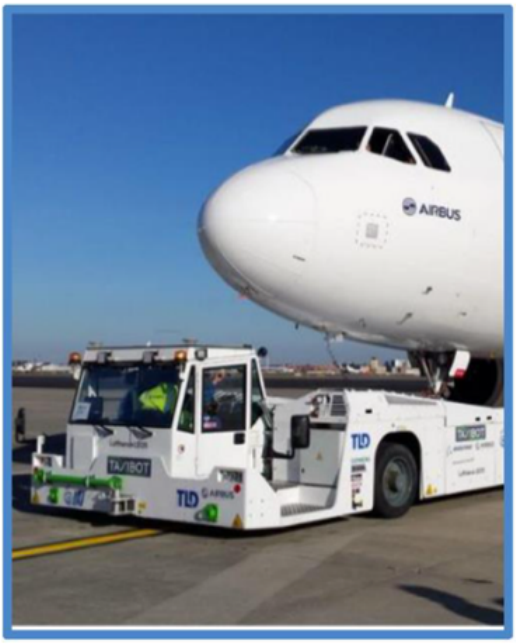

Figure 12: Towing vehicle coupled to an aircraft

This solution is used to perform aircraft ground movements around the airport from gate areas or remote stands to the runways and vice versa.

During Sustainable Taxiing, where operations are using the on-ground taxi solution, the control of the convoy lies with the PIC of the aircraft, who can steer the aircraft using the regular controls in the cockpit. Since the bypass pin has been taken out of the nose landing gear (NLG) of the aircraft, the nosewheel will turn, allowing these inputs to be received by the cradle of the on-ground solution. The vehicle will mirror these inputs and replicate the desired aircraft behaviour using wheel steering system (some systems increase manoeuvrability by using a four-wheel steering system). On-ground taxi solutions are capable to accelerate the aircraft convoy up to 22 knots (some even more). Braking can be performed by using the aircraft's main landing gear, with the on-ground taxi solution responding to the resulting drag. In this way, the aircraft's NLG doesn't experience high loads or fatigue events and stays within design parameters.

During an outbound mission (departing aircraft) the tug driver is in control of the loading of the aircraft onto the on-ground taxi solution (after communication with the Flight Crew) as well as the subsequent pushback or push-pull. After this, the Flight Crew can carry out Engines-off Sustainable Taxiing through use of a Sustainable Taxiing Vehicle by taking over the control of the vehicle (during which the tug driver remains inside the vehicle but has relinquished control). The cockpit crew can taxi to the unloading location, and either start-up (and stabilise) their engines towards the end of the taxiing time, during or after unloading. The unloading of the aircraft from the vehicle is done once again by the tug driver (who has regained control). After unloading and clear signalling between tug driver and cockpit crew that the tug driver is in a safe spot, the Flight Crew can taxi towards the runway on the aircraft's engine power. The tug driver returns the empty vehicle to the terminal area to carry out a next mission. The lack of engine intake or engine blast risks might positively influence risk and improve risk mitigation in the vicinity of aircraft stands (this is also true for on-board solutions).

Pushback and Taxi-out

During the taxi-out phase the pushback is performed in the same way as normal operations. When the pushback is completed, controls are handed over to the pilot. The Flight Crew controls the tug in the same way as normal taxi operations, steering via tiller and nose gear and braking via the aircraft brakes. No thrust needs to be applied, as tug vehicles accelerate automatically when brakes are not applied.

While taxiing, the aircraft APU supplies power to the aircraft electrical, hydraulic and air conditioning systems. The system provides the same turning radius of a normal aircraft, with the added benefit of having better traction in slippery conditions. Furthermore, a significant number of aircraft require no modifications to use towing vehicles, even though the aircraft will need to be certified to be operated in this way.

In the taxi-out phase, the tug vehicles need to be coupled at the "(un-)loading point" on the apron, also called "coupling point" in the AEON CONOPS Document, and cleared for pushback by the Ground Controller to the Flight Crew who will relay that message to the pushback Ground Handling staff. Once coupled, the Tug Driver will handle pushback operations in the same manner as it is done today. As soon as pushback is completed, the control is handed over the Flight Crew to taxi until the uncoupling ('unload') area.

Taxi in

During the taxi-in phase, the aircraft will be connected to an on-ground taxi vehicle stationed at an area as close as possible to the arrival runway taking into account engine cool-down. The Ground Handler in charge of the on-ground taxi vehicle is positioned at a safe designated area at the (un-)load point for stand-by ground equipment. When the aircraft arrives at the (un-)load point, communication needs to be established between the Ground Handler and the Flight Crew in order to indicate it is safe for the Ground Handler to approach the aircraft. The Ground Handler attaches the vehicle to the aircraft nosewheel and establishes the communication cable to facilitate direct communication between Flight Crew and Ground Handler.

3.2.1.4.4 Dispatch Towing (On-Board Solution)

An alternative form of sustainable taxi (towing) operations is dispatch towing, whereby the aircraft will be towed from the gate/aircraft stand toward the departure runway. The main difference with the other on-ground solution described above is that the towing vehicle will move and steer the aircraft, not the Flight Crew. The traditional tow operations are only suitable for aircraft at lower speeds and weight. To avoid an overload of the nosewheel construction, towing operations is not possible at normal taxi speed and closer to MTOW.

Normally, the maximum amount for towbar less towing for flight (dispatch towing) is limited 25% of total flight cycles. This is because the use of dispatch towing may result in reduced service life of the nose landing gear.

So far, dispatch towing has not become very popular due to abovementioned limitations and other factors like return of the towing vehicle to the terminal area. If these challenges will not be overcome, it is likely that dispatch towing won't become one of the preferred sustainable taxi options described earlier in this chapter. For these reasons, dispatch towing will not be further elaborated in the next chapter(s).

3.2.1.4.5 Concept of hybrid Sustainable Taxi Operation

Some Sustainable Taxiing (STX) systems may have limited capabilities to taxi a (heavy) aircraft upslope or provide insufficient traction on extremely wet and slippery surfaces. This is especially true for on-board systems that drive the nose gear only. In these cases, the STX solution cannot be used, and the main engine(s) need to be used instead. Alternatively, a hybrid mode can be used whereby the STX system is used together with one aircraft engine, although this significantly decreases the environmental performance. This combination will provide sufficient (break-away) thrust to get the aircraft moving. In such cases where STX operations is limited, a different taxi-routing could possibly be allocated by ATC to be able to perform STX operations.

This can be one type of aircraft applying different modes of operation during the taxi-out or taxi-in process, multiple types of aircraft using one mode of operation or multiple types of aircraft using different modes of operation.

3.2.1.4.6 Conceptual presentation of Sustainable TAXI-OUT

Taking into consideration the different sustainable taxi-out solutions and summarizing the high- level steps, a harmonized high-level concept for sustainable taxiing is presented in the Figure 13. Compared to conventional taxiing, sustainable taxiing introduces a sustainable taxiing phase, with a taxi clearance and the actual Sustainable Taxi operation, that precedes the taxi (with aircraft engines) phase and those delays (and that physically repositions) conventional taxi concept elements (engines start, unloading, and taxi clearance by ATCO).

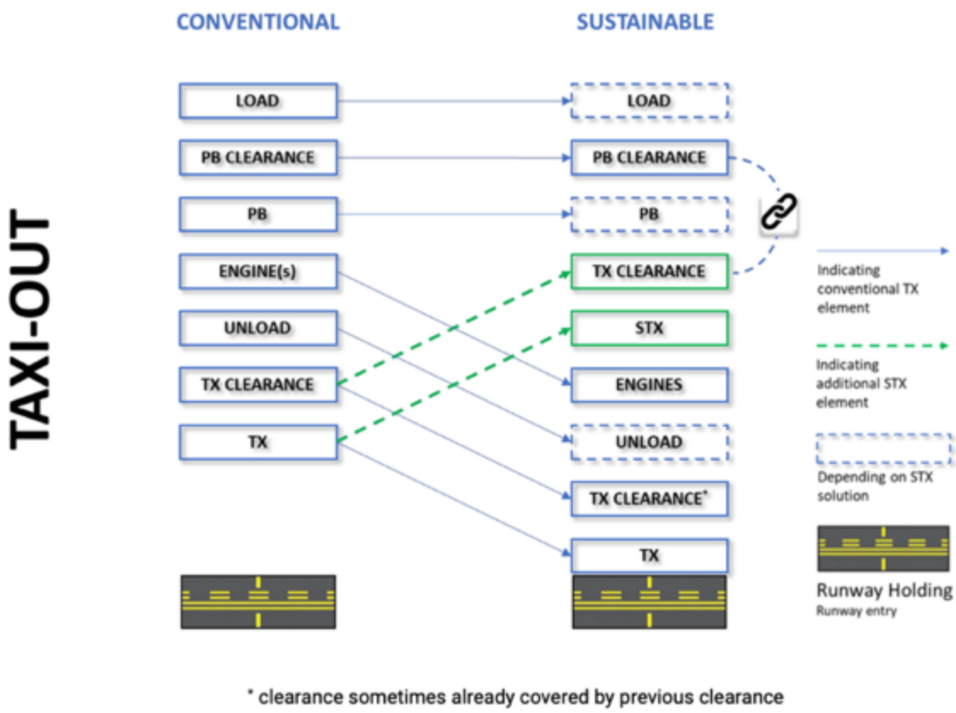

Figure 13: (Hybrid) Sustainable Taxi-Out Concept

3.2.1.4.7 Conceptual presentation of Sustainable TAXI-IN

Taking into consideration the different sustainable taxi-in solutions and summarizing the high- level steps, a harmonized high-level concept for sustainable taxiing is presented in the Figure 14. Compared to conventional taxiing, sustainable taxiing introduces a sustainable taxiing phase, with, in case of application of on-ground solutions, additional loading and unloading of the aircraft to sustainable taxi solutions, and additional TX clearance and the actual STX operation, that follows the initial taxi-in

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phase (with aircraft engines) phase. The sustainable taxi-in concept advances (and physically repositions) the conventional taxi concept element, engines off.

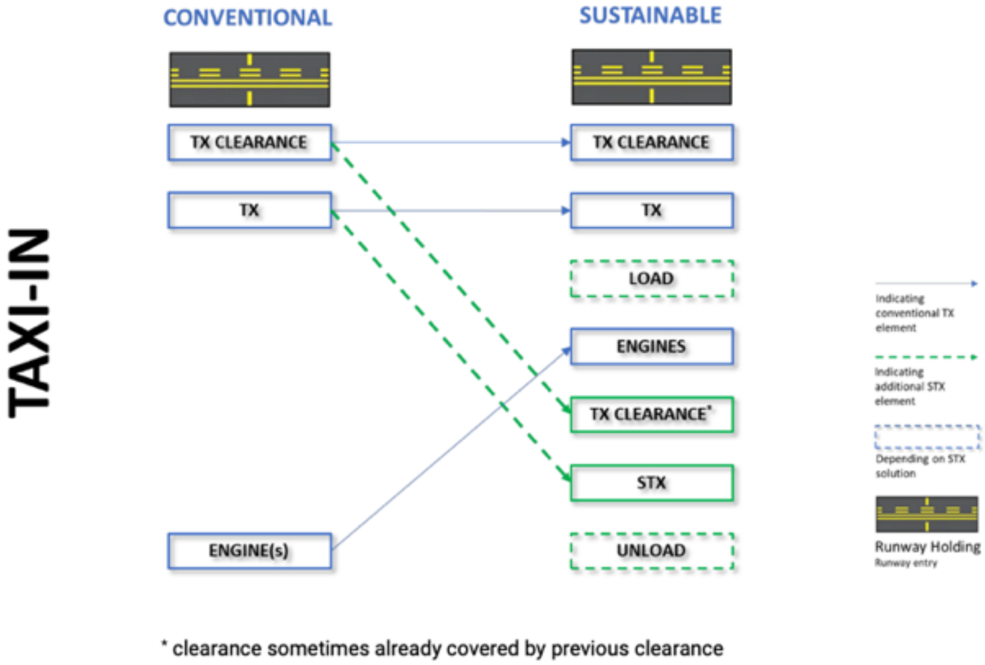

Figure 14: (Hybrid) Sustainable Taxi-In Concept ASTAIR Operation

3.2.2 Concept summary

While the most significant reductions in fuel consumption and noxious emissions in aviation occur during flight, these optimizations for aircraft trajectories are contingent on each flight adhering to its schedule. As a result, improving departure punctuality and smoothing trajectories become essential for realizing the full benefits of in-flight optimizations. Today, ground operations are managed by a human operator assisted with decision support tools. In addition, emergence of engine off taxiing techniques will raise the number of vehicles to guide because of additional towing tugs. Increasing the level of automation thanks to an Artificial Intelligence (AI) capable of planning conflict-free trajectories, for both departures and arrivals given their interdependent nature, and manage the routine movements autonomously on behalf of the operator, could help increase the general predictability of airport turnaround operations.

The solution aims at improving predictability, safety and efficiency on large airports implementing A-CDM and equipped with A-SMGCS, it would upgrade the guidance service to make it more autonomous. The solution 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. SESAR solution Ecological routing with speed profiles can forecast 20 minutes of conflict free vehicles trajectories, using speed regulations. The solution centralizes information from different stakeholders to feed the routing computation and provides relevant results according to stakeholders' roles. It will provide routing information to ATCOs, gives clearances with speed profiles to aircraft and tow tugs, and communicates tow tugs allocation to the Tug Fleet Manager (new role introduced in the AEON

Concept of Operations, see 3.2.2.1.1). All these data will be updated in real time to adapt to the operational events.

Concerning a departure flight, A-CDM will be the entry point for Airspace User or representative Ground Handler to potentially modify TOBT of a flight up to 5 minutes before actual time, which will be delivered to TWR control following the computed departure sequence. A new TSAT is then delivered and ASTAIR can take it into account in the next computation round. 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 computed by ASTAIR AI, the human operator will have the possibility to specify various constraints or input new information to AI to facilitate the ground movements and handle specific operational events.

The solution involves computing conflict-free routes for ground vehicles through effective collaboration between human operators and AI systems. Conflicts are resolved by adjusting vehicle speeds, and the clearances, routes, and speeds are electronically transmitted to each vehicle. A key enabler for this approach is ensuring that vehicles can precisely follow the assigned routes and speed orders. This can be implemented using systems such as dispatch tow tugs, autonomous taxiing aircraft or automated follow-me cars, which are all being currently under development.

The principal difference with current operations is that ASTAIR solution proposes the integration of incoming flights in advance by the ATCOs so they can build a mental image of the coming traffic on the platform up to 20 minutes ahead, instead of reacting to pilots' requests as they come. In order to help the ATCO understand the plan the AI has computed and facilitate trajectories integration, ASTAIR proposes an additional tool to analyse results provided by AI. It consists first of an analysis of each vehicle trajectory to detect anormal speed up or down to detect regulations applied for deconfliction and in a second step, all trajectories are analysed altogether to detect potentially conflicting situations. Even though all trajectories computed by the multi agent system are deconflicted via speed control in theory, some crossings can still lead to situations where several aircraft coming in the same intersection in a short period of time. These situations, once detected, shall be displayed during future trajectories integration and on the real time radar image as a reminder to the supervisor to check that there is no safety issue. This process of trajectories integration in advance can also be applied to the Tug Fleet Manager. Indeed, the TFM could supervise empty tugs movements in the same manner ground ATCO deals with aircraft and tugs coupled to aircraft.

Current operations	ASTAIR operations
Aircraft (a/c) and vehicles follow route cleared by ATCO at their own speeds	AI gives speed clearances that ensure conflict free route and safe distances. ATCO manages unexpected events.

ATCO constantly monitors all traffic in real time and clears all movements.	ATCO integrates new traffic in advance with AI computed routing proposition. AI manages traffic and ATCO supervises for safety
ATCO clears departure a/c for push back and routing	ATCO clears departure a/c for pushback and AI sends routing and speed clearances autonomously
ATCO clears arrival a/c after runway vacated for routing	ATCO integrates new arrival traffic and AI sends routing and speed clearances autonomously
TFM guide tugs driver until a/c to be towed	TFM validates the mission, and AI sends routing and speed clearances autonomously

Table 3: ASTAIR operations impacts summary

Some examples of the actual implementation of this concept as it has been used for the validation exercise can be found in appendix 7.1.

3.2.2.1 Integration with other solutions

In previous AEON project, the CONOPS designed and assessed interconnected solutions to enable an optimized allocation of a fleet of tugs to aircraft, predefined routing providing speed profiles to avoid conflicts, dedicated HMI for Air Traffic Controllers as well as a new role, the Tug Fleet Manager. The integration apported to the A-CDM and the algorithms and HMIs developed for a proper implementation of this solution. AEON project developed the following systems:

- Integration with A-CDM
- Tug Fleet allocation tools
- Multi Agent path planning tool
- User interfaces and interaction
- Tug fleet management HMI
- Radar image
- Moving map.

AEON developed these systems to provide support to ground controller with ATC-side computed routing and speed profiles displayed in a stripless control interface with interaction to update the suggestions or coordinate with the tug fleet manager.[17]

The first requirement for AEON implementation concerns an integration with the Airport Collaborative Decision Making (A-CDM) platform to support discussion and negotiation of the desired taxi technique for the aircraft between the stakeholders. Beyond negotiating actions, AEON aims to obtain a new pre-departure sequence (PDS) tool. To achieve the best optimised use of engine-off techniques, the AO/GH are provided with real time towing fleet availability or internal on-board system availability (autonomous taxiing solutions or SET) options to be chosen at EOBT-3 hours (when the flight plan is filed) and confirmation of change of system (if required by AO/GH) at EOBT – 60 min. This would enable the A-CDM platform to calculate the TSAT for the said aircraft. The PDS tool acts as a dashboard and collates data for both arrival and departure of flights. AO/GH can file their flight plan EOBT- 3 hours,

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while the CTOT is issued EOBT-2 hours and the TSAT is provided based on the airside/network capacity constraints anytime between TSAT – 40 min to TSAT – 10 min.

The new PDS platform should provide information to the AO/GH to choose and update their preferred possible taxiing technique.

3.2.2.1.1 Management of non-autonomous engine-off taxiing operations by Tug Fleet Manager

Previous SESAR project AEON proposed an ATM solution that helped the integration of Taxibots fleet in ATC traffic with a dedicated working position [20].

Depending on the economic model applied, the deployment of tug vehicles could be proposed either by the airport operator (APTO), the airline operator (AO) or the ground handling company (GH). The most efficient is certainly to share the vehicles over different companies with a pooling system, thus owned by the airport and operated by one single entity. The assumption that the tugs are well always maintained and operated by the APTO/AO/GH and the entire fleet management responsibility rests with the Tug Fleet Manager (TFM).

3.2.2.1.2 Ecological routing with speed profile

The multiagent system model for routing of aircraft and towing vehicles developed in SESAR AEON project will be extended in ASTAIR in three ways:

- Motion planning algorithms will be calibrated using historical track data and findings from projects such as EVOLVE and OWHEEL to realistically represent the kinodynamics of all vehicles. This includes the phases of acceleration, deceleration, traversing turns and straight segments.
- The routing algorithms will be extended to be able to take into account different types of ATCOS' constraints (e.g., priority constraints, spatio-temporal constraints).
- Since routing algorithms are supposed to be used in real time, further work on acceleration of computational time required for trajectory planning will be performed.

EVOLVE: Motion planning and control in the safety-critical situations (NWO Open Technology Programme, project 18484) [17]

EVOLVE proposes to use an enhanced physics and data-based learning approach to the control of automated driving hazardous driving scenarios known as "edge cases" where representative data are statistically rare. The developed control algorithms will handle and guarantee safety during evasive manoeuvres for collision avoidance, something that current automated driving cannot guarantee.

Motion and Simulator Sickness: Modelling, Prediction and Applications (Toyota – TUD TKI HTSM)[17]

This project investigates comfort-oriented motion planning and human-automated vehicle interaction.

OWHEEL: Benchmarking of Wheel Corner Concepts Towards Optimal Comfort by Automated Driving (EU H2020-MSCA-RISE-2019 OWHEEL, project 872907) [17]

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The project OWHEEL aims at the development and evaluation of new concepts of automotive wheel corners as crucial elements of future vehicle architecture tailored to provide an optimal comfort during automated driving. The consortium will benchmark four essentially different classes of corners: Passive with specific wheel positioning; Passive composite; Active with ordinary ride dynamics control; Active with integrated wheel positioning control. For each proposed concepts, the project will include relevant stages of development design, extensive simulation studies and experimental validation. The main goal of the OWHEEL project is to perform a deep analysis and provide on its basis the recommendations for future automated vehicle architecture.

3.2.2.1.3 Human Automation Teaming

The concept of human automation teaming in ASTAIR project is developed upon the results of Take Control (TaCO) SESAR 2020 exploratory research project.

TaCo aims to define an automated system sufficiently powerful to both accomplish complex tasks involved in the management of surface movements in a complex airport and self-assess its own ability to deal with non-nominal conditions. When needed, such system should be sensitive enough to transfer responsibilities of traffic management back to the controller, in a timely and graceful manner and in way that makes him/her comfortable with the inherited tasks.[18]

TaCo allows Air Traffic Controllers to progressively create and tune automation with visual constructs that also assist them in understanding the behaviours, hence facilitating the handover if required. The concepts for programming or representing automation explicitly on top of the airport map could be reused for certain tasks such as giving a priority to specific areas or creating safety nets according to the supervisor preferences.[17]

One important enabler for ASTAIR concept on automated ground movements, is that supervised vehicles are able to follow a routing clearance associated with a speed profile that allows deconfliction. Although today aircraft do not have this ability, it seems a good assumption that in the near future it becomes possible. Either large airports will adopt widely on-ground or dispatch towing solutions [9] or new generation of aircraft will come with autonomous taxiing feature implemented. This assumption is reinforced by Amsterdam Schiphol airport plan to have 100% of inbound and outbound traffic towed by 2030, the different live trials and operations of Taxibots and Airbus ATTOL project:

Amsterdam Schiphol roadmap 2030

By 2030, sustainable taxiing will be standard procedure at Schiphol. The airport recently presented a roadmap describing the steps that will be taken to reach this goal [23].

Taxibots system

Taxibots[27], specifically designed for aircraft towing, are robotic vehicles that assist in moving planes on airport taxiways without the need for traditional tug vehicles. These autonomous systems are equipped with advanced technology, including GPS and high-precision sensors, enabling them to manoeuvre with accuracy and efficiency. Taxibots connect to the aircraft's nose gear and can tow it to and from gates, runways, and maintenance areas. The use of Taxibots contributes to fuel savings and fewer carbon emissions, as they operate on electric power.

Airbus Autonomous Taxi, Take-Off and Landing (ATTOL) project

The ATTOL project[26] was initiated by Airbus to explore how autonomous technologies, including the use of machine learning algorithms and automated tools for data labelling, processing and model generation, could help pilots focus less on aircraft operations and more on strategic decision-making and mission management. Aircraft implementing autonomous taxi feature would be able to follow correctly and automatically a routing clearance including speed constraints.

Autonomous "follow-me" cars

Another non-intrusive solution, from aircraft point of view, consist in automated "follow-me" cars [28] remotely piloted by ATC with A-SMGCS. It would show the pilot the way to go but could also regulate its speed, helping in the implementation of routing clearances with speed constraints.

3.2.2.1.4 Extended airport safety nets for controllers at A-SMGCS airports

The solution PJ.02-W2-21.1 aims at enhanced Safety for airport operations as Support Tools for controllers at A-SMGCS Airports to detect potential and actual conflicting situations, incursions and non-conformance to procedures or ATC clearances, involving mobiles (and stationary traffic) on runways, taxiways and in the apron/stand/gate area as well as unauthorised/unidentified traffic. Controllers are provided in all cases with the appropriate predictive indications and alerts.

In particular, the solution defines Conformance Monitoring Alerts for ATC that could be integrated in ASTAIR concept, especially to show ATCO when an automation failure occurs on vehicles side. For instance, a ROUTE DEVIATION alert shall be handled by the ATCO in case ASTAIR AI cannot propose a solution in due time. In the same manner, a HIGH-SPEED alert is described, in ASTAIR scope it could be completed with a LOW-SPEED alert to ensure the vehicles are finely enough following the speed clearances set by ASTAIR AI.

In addition, the Conflicting ATC Clearances (CATC) function could help ensure a safe collaboration between the ATCO and ASTAIR AI by ensuring that orders that can be given manually by ATCO are not incompatible with automated clearances.

3.2.2.2 Stakeholders

Implementation of ASTAIR concept requires the involvement of all main stakeholders, such as:

3.2.2.2.1 Airport Operator (APTO)

APTO is intended as a natural or legal person engaged in or offering to engage in an airport operation. In ASTAIR, APTOs are required to take part in the strategic long/medium-term planning phase accepting or suggesting the most profitable taxiing techniques [16].

As the allocation of parking stands falls under the responsibility of the APTO (which may be delegated at times), the APTO would also play a role in the tactical phase. This involvement includes scenarios such as dealing with arriving aircraft without available parking and considering any suggested modifications to parking stand assignments by AI. It is also important to consider compatibility of parking stands for operations with Taxibots. There would be need to check if the stand is suitable for manoeuvring tugs while entering on the stand and before leaving the stand. The role of APTO is to provide also this list of compatible stands.

Besides aircraft parking, the use of Taxibots in taxiing technique also requires personnel who specifically manage schedules and allocate tug fleet under the APTO's management. This personnel is known as Tug Fleet Manager (TFM). TFM is an actor introduced by the AEON CONOPS. It is intended to support ATCOs in the safe and fair management of taxiing operations. This subject is devoted to the efficient allocation and safe dispatching of tugs according to the traffic conditions of the airport. TFM is considered a single person, but the role can be performed also by a group of individuals. [16]

Furthermore, APTO has also a prominent safety role. To be able to achieve the aims of that role, Commission Regulation (EU) No 139/2014 lays down requirements and administrative procedures related to aerodromes, one of them specifies the Management System. APTO shall implement and maintain a management system integrating a safety management system. This management system includes definition of roles, responsibilities and accountabilities, safety policy, hazard identification process, risk management process, safety performance management, safety training and communication, coordination of safety management systems with other organisation and compliance monitoring.

The change management process at the APTO aims to:

- identify changes within the aerodrome operator’s organisation, management system, the aerodrome or its operation which may affect established processes, procedures and services.
- describe the arrangements to ensure safety performance before implementing changes.
- eliminate or modify safety risk controls that are no longer needed or effective due to changes in the operational environment.

ASTAIR concept with use of AI for suggestion of most profitable taxiing techniques, the assignment of parking stands and use of Taxibots in operations at the aerodrome will affect organisation, operations, processes, coordination with partners, and potentially would require changes in the infrastructure and airport systems. As such, in the safety management system, the ASTAIR new operating method is identified as a "change". The formal change management process shall be applied to analyse and evaluate all impacts and potentials hazards for safety. Actions and measures will result for this process preparing a safe introduction of changes in the future operations at the aerodrome in collaboration with all impacted partners.

The aerodrome operator shall document all management system key processes. The management system shall be proportionate to the size of the organisation and its activities, considering the hazards and associated risks inherent in these activities. In the case that the aerodrome operator holds also a certificate to provide air navigation services, it shall ensure that the management system covers all activities in the scope of its certificates [19].

ASTAIR concept falls inside a future airport operation scenario and aim to help increase the general predictability of airport turnaround operations and cope with the additional complexity induced by engine-off taxiing techniques.

Real time data sharing in A-CDM through the new system can lead to reduced congestion, enabling smoother airport operations. Furthermore, efficient ground operations, supported by this project, can reduce environmental impact and noise pollution around airports.

3.2.2.2.2 Ground Handling Service Provider

In the context of the ASTAIR concept, the ground handling services that have a direct connection are Pushback Operator and Tug Driver.

- Pushback Driver is a ground handler specialised in pushback operations. This role is impacted by both autonomous and non-autonomous taxiing techniques. Pushback operations with autonomous solutions will be handled by the PIC, while the introduction of non-autonomous techniques will require drivers.[16]
- Tug Driver (TD) is a ground handler specialised in operating towing vehicles. Usually, this subject has specific duties during pushback manoeuvring. In the AEON solution, the driver gives control to the pilot in command after performing pushback and only drives on the taxiways when the tug is not coupled (i.e., empty), according to the instructions respectively provided by the Apron Controller and Ground Controller. Furtherly, s/he interacts with the Tug Fleet Manager (TFM) whose provide instructions for new missions [16].

With ASTAIR concept, the ground handlers can optimize operations with better predictability of operations and use of different taxiing options [17]. On the other hand, they need to receive training to enhance their competence in line with the technological advancements incorporated in this concept

3.2.2.2.3 Air Navigation Service Provider (ANSPs) and Air Traffic Service Providers (ATSPs)

ANSPs and ATSPs generally include the services provided by ATCO working at airports for the arrival and the departure flight phases, and in Air Traffic Control Centres (ACCs) for the en- route flight phase [16]. ATCOs play a crucial role in ensuring safe and efficient air traffic management. With the implementation of ASTAIR, ATC in charge of managing traffic on the ground where automation of certain tasks could improve human performance. Same as AEON, in ASTAIR, the most impacted subjects will be airport ATCOs and, more specifically, the Apron Controller (AC) and the Ground Controller (GC). Indeed, these shall coordinate their activities with the ones performed by the TFM and supervise the taxiing operations according to route clearances and speed profile provided by the ASTAIR system.

ATC will benefit from improved operational efficiency, enhanced safety, and reduced costs. The new system will provide real-time data sharing, interoperability, and automation, which will streamline operations and enable ATC to manage increasing air traffic demand.

APTO of very large and large airports where surface traffic management is under his responsibility, with better use of the human resources with automation of selected non-safety critical tasks [17].

3.2.2.2.4 Airline

- **Aircraft Operators, or Airlines,** are intended as natural or legal persons engaged in or offering to engage in air services. In ASTAIR, aircraft operators are required to take part in the strategic long/medium-term planning phase accepting or suggesting the most profitable taxiing techniques for their scheduled departing or arriving aircraft [16].

  One of the most significant impacts of ASTAIR is the potential for increased efficiency and reduced costs. By automating the taxiing process, airlines can save time and fuel, which can lead to significant cost savings. On the other hand, the initial cost of installing systems in

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airports and aircraft can be substantial. Implementation of ASTAIR may face hurdles related to integration with existing airport infrastructure and aircraft systems, as well as compatibility issues between different manufacturers' equipment. Addressing these challenges may require additional time and resources from both airlines and airports alike.

- **Pilot (Flight Crew)** is intended as the personnel responsible for the operation of an aircraft during the flight. The two main actors are the PIC and First Officer (FO). With the implementation of ASTAIR SESAR, it has advantage in the reduction of workload and stress during taxiing operations. ASTAIR can automate the taxiing process, allowing the flight crew to focus on other critical tasks, such as communication with air traffic control, system checks, and passenger safety. This can lead to improved situational awareness and a safer overall taxiing experience. Additionally, it can potentially enhance the precision and efficiency of taxiing operations. By utilizing A-SMGCS technology and advanced algorithms, ASTAIR can guide the aircraft smoothly and accurately to its designated gate or runway holding point, minimizing the need for manual steering adjustments by the flight crew. This can help reduce delays, improve on-time performance and prevent conflict on manoeuvring area by following speed profile, which is crucial for maintaining a smooth airport operation.

3.2.2.2.5 Regulator or National Aviation Authorities (NAAs)

Regulators play a vital role in ensuring safety and security in the aviation industry. The implementation of ASTAIR will require regulatory oversight to ensure compliance with new standards and procedures. Regulators will need to adapt existing regulations or develop new one to facilitate seamless integration of the system within the aviation ecosystem.

3.2.2.3 Key scenarios

In this section, several scenarios related to aircraft ground operation that occur in the airport will be presented. Other use cases may be developed later.

The various interviews[2] also enabled to draw up a list of use cases that would help to test the concept, study its operational feasibility and design the tools needed to implement it. In addition, to normal operations of inbound and outbound traffic taxiing on a low to normal load, the other use cases featured unexpected event that were not in the planning given to AI algorithms and impact the ground operations in short delays.

In the following sub-chapters describing the use cases sequences, some references are made to a zoom in, it actually refers to Figure 15 and Figure 16 below showing the process for the ground ATCO (Zoom (1))or TFM (Zoom (2)) to analyse a trajectory and decide whether to give authority to AI to handle autonomously the vehicle.

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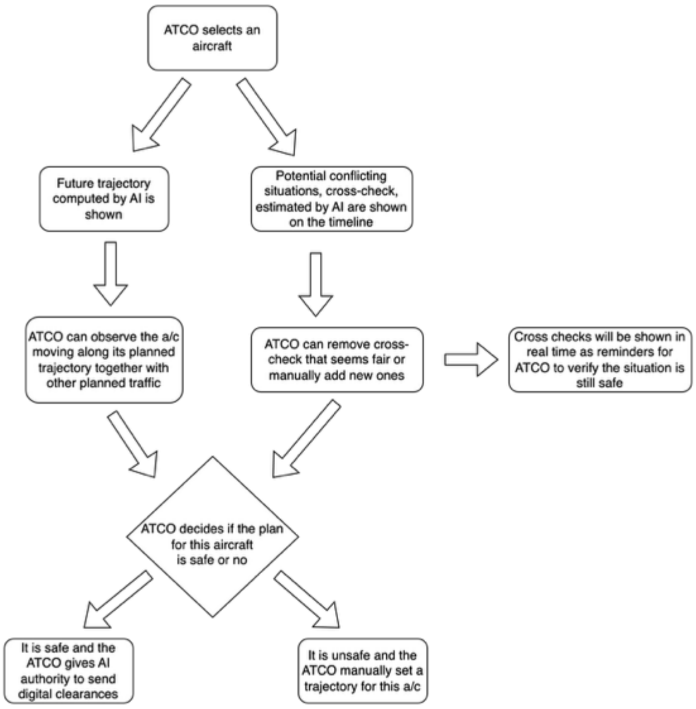

Figure 15: Zoom (1) on trajectory integration for ATCO

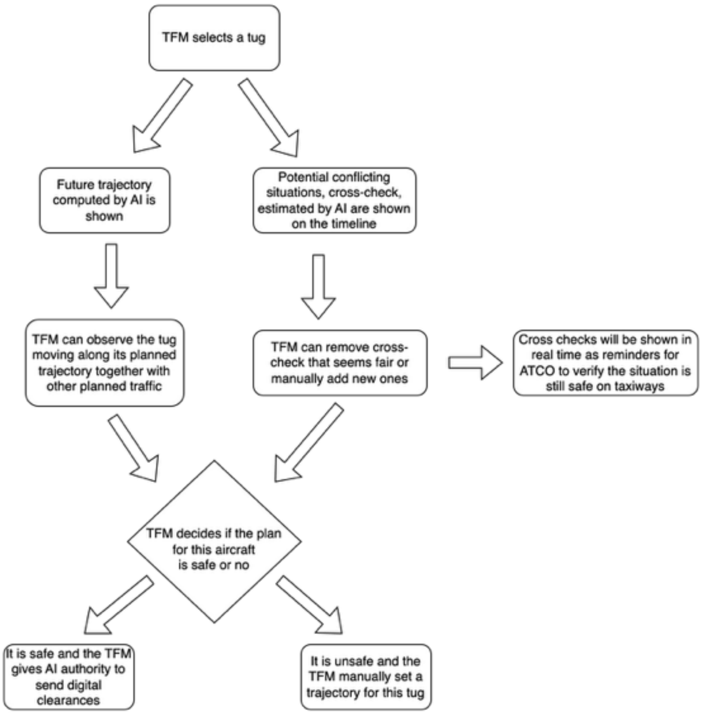

Figure 16: Zoom (2) on trajectory integration for TFM

Concerning the communication between pilots and ATC, ASTAIR solution proposes to modify the workflow between to facilitate future trajectories integration and give valid inputs to the algorithm that computes the conflict free trajectories:

- For a departure flight, the pilot would contact ground ATC a few minutes before TSAT to confirm it.
- For an arrival, arrival managers are already precise 10 minutes in advance on the estimated time of arrival, nevertheless uncertainty remains on the actual runway exit.

In the end, all first contacts are made over radio and continue on datalink if the ATCO gives authority to AI to guide the aircraft.

The different levels of automation found in the use cases can be summarized as:

- 1A with manual operations:
    - data input in A-CDM about flight schedule and taxi technique
    - manual verification that the situation is safe for specific actions (push back and engine startup)
    - manual handling of unexpected situation that needs high reactivity (UC9)
- 2A/2B with human/AI collaboration:
    - The operator checks the solution proposed by AI and decide to give or not authority to AI for vehicle guidance
    - The AI requests the operator assistance to check potential unsafe situations (push back and engine startup) or suggests operation to pilot (engine start-up)
    - The automated solution is modified due to operational events and to be re-validated by the operator
- 3A: AI guides the vehicles throughout the taxi phase.

3.2.2.3.1 Use case 1 – Normal operation

In normal operations, AI would compute the conflict free routes in advance to ensure target take off times and target in block times and send the routing and speed clearances as soon as the human operator has cleared the vehicles for movements. While the vehicles are moving, AI will check that the actual positions are matching the computed positions. If minor discrepancies occur the AI will recompute the routes and raise alerts if important differences are found. Alerts may concern wrong directions or inadequate speeds that would create potential conflicting situations.

Normal operations for departure and arrival aircraft are derived in two sub use cases, with and without the use of tow tugs. The introduction of towed aircraft impacts the number of actors involved but also the management of engines start-up, which is not specific to ASTAIR (but to sustainable taxiing even not automated), however the artificial intelligence can help optimise the timings of the start-ups. The normal operation aims at engaging operators with the AI system and foster trust in the AI system.

3.2.2.3.1.1 Use case 1a (UC1a) – Departure with Taxibot

This use case (Figure 17 and Figure 18) describes a normal departure of an aircraft using a Taxibots. The pre-conditions show the aircraft ready to depart and waiting at the gate, while the Taxibots are available and ready to be used. This is the procedure using the AI, without considering delays or other constraints/inconveniences.

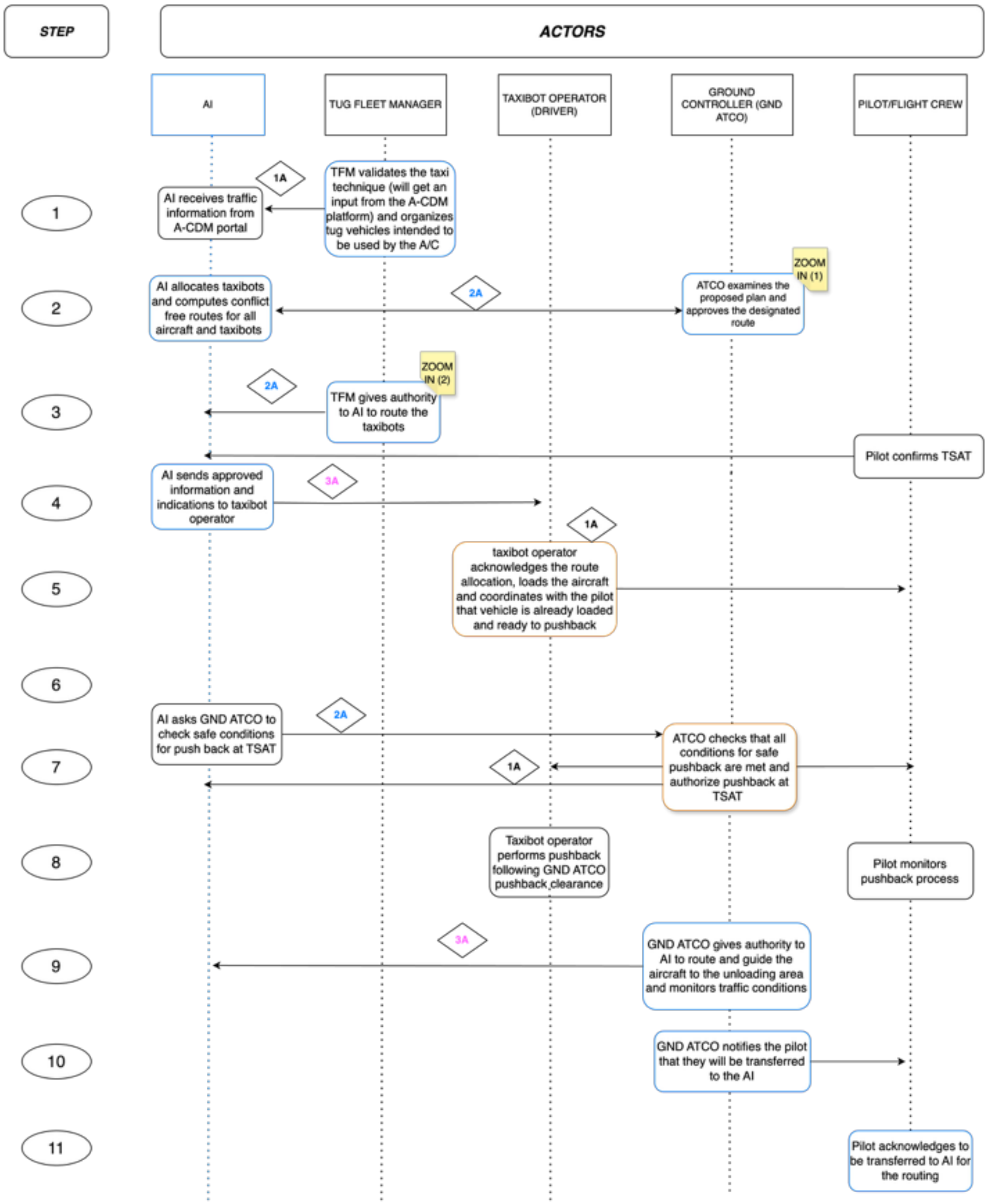

Figure 17: UC1a Departure with Taxibot sequence diagram (part 1)

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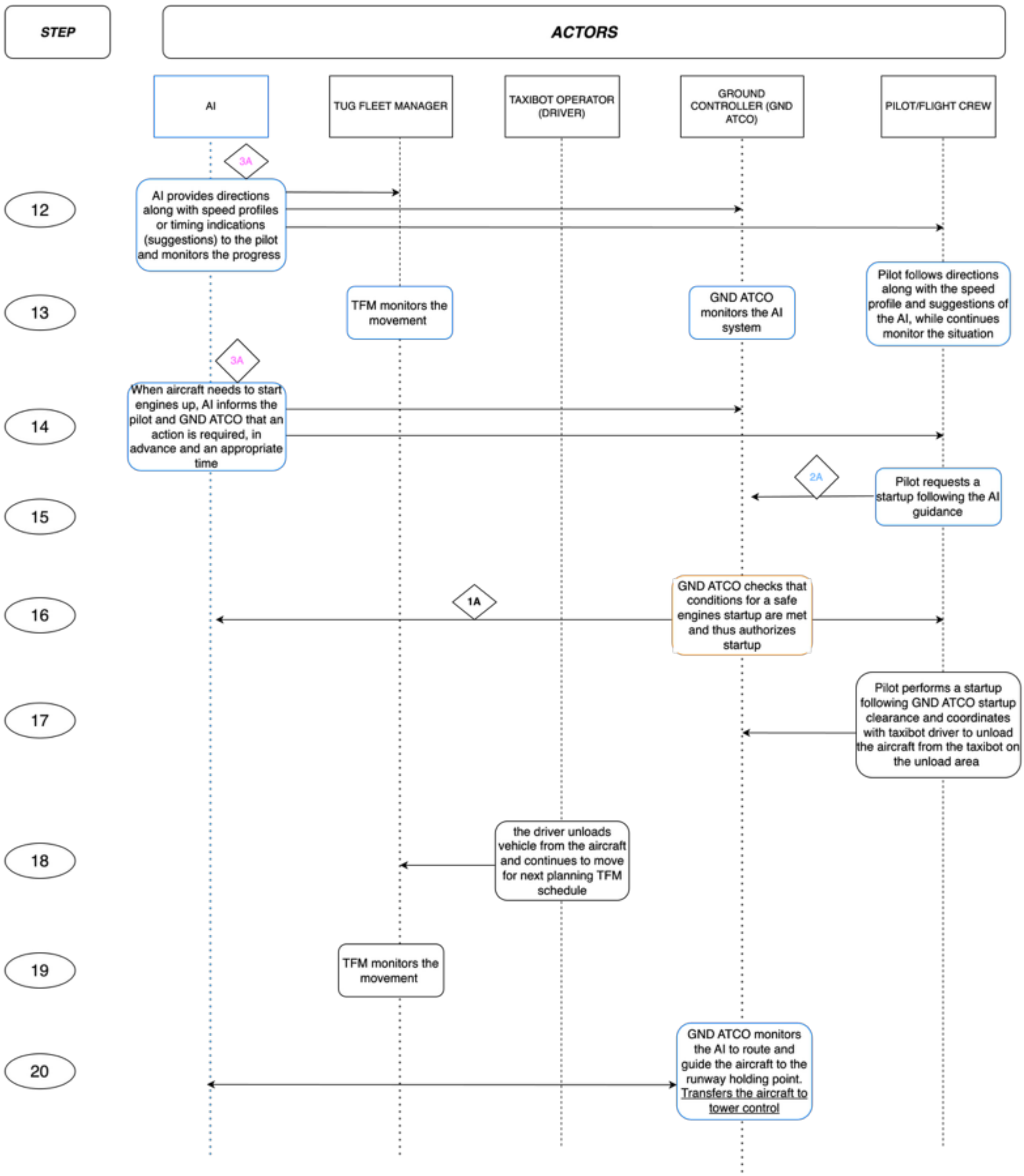

Figure 18: UC1a Departure with Taxibot sequence diagram (part 2)

3.2.2.3.1.2 Use case 1b (UC1b) – Arrival with Taxibot

This use case (Figure 19) describes a normal arrival of an aircraft using a Taxibot. The pre-conditions show the aircraft transferred from TWR ATCO to GND ATCO and ready to taxi and waiting at (un)load area, while the Taxibots are available and ready to be used. This is the procedure using the AI, without considering delays or other constraints/inconveniences.

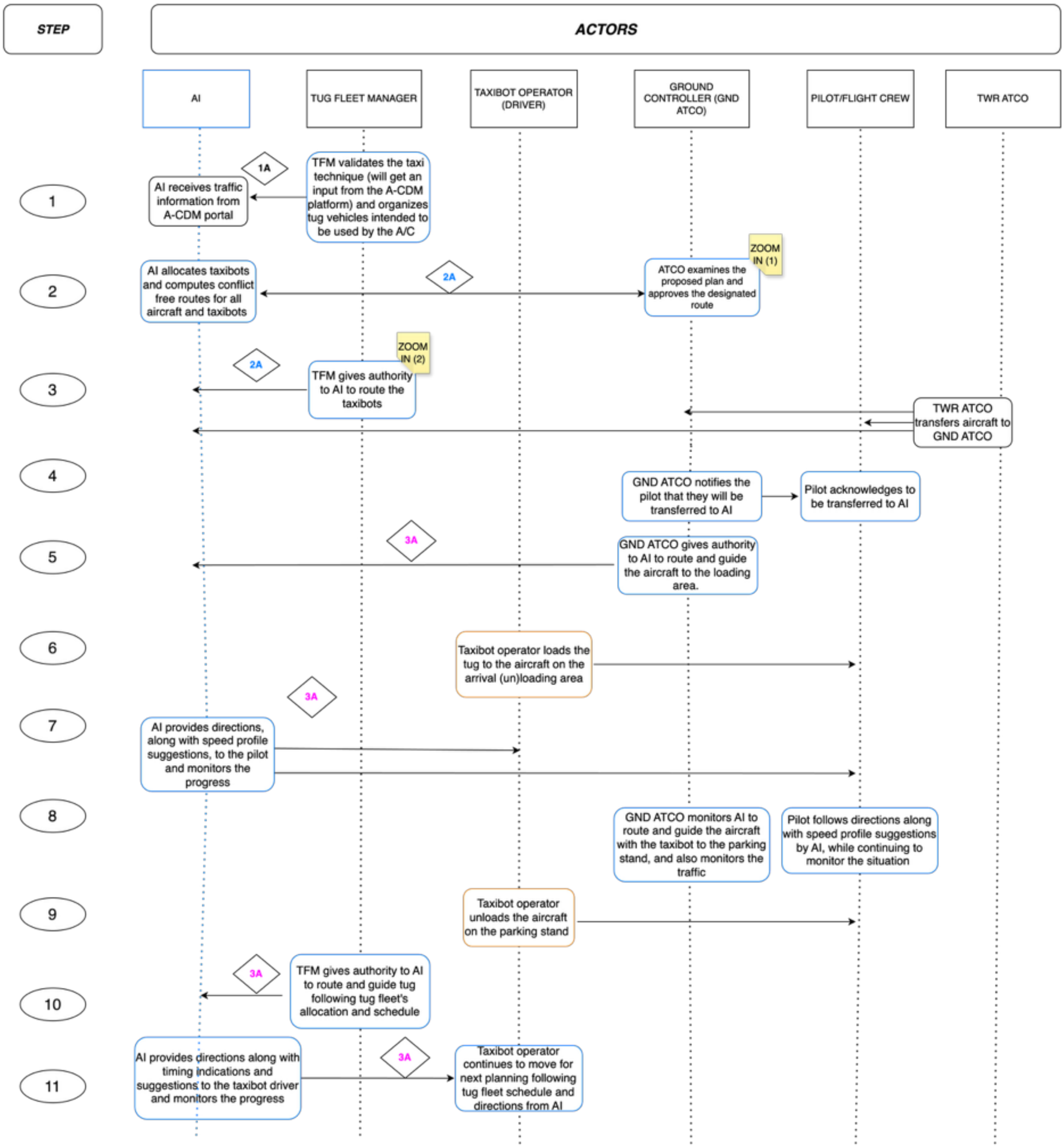

Figure 19: UC1b Arrival with Taxibot sequence diagram

3.2.2.3.2 Use case 2 (UC2) – Normal operations with rescheduling

The first operational event to be studied will be rescheduling a departure, for instance because of a passenger being late. It is presented in Figure 20 and Figure 21.The delay information may come from different sources, either A-CDM or AMAN sequence for instance. AI shall take the new timing into account, recompute a solution and give it to the supervision. The aspect under investigation here is the impact of the time needed for the AI to integrate this new information and how the system should behave in the meantime, the operational constraints it would add on the normal workflow. The visualisation of the impacts of one rescheduling over other traffic is also considered here.

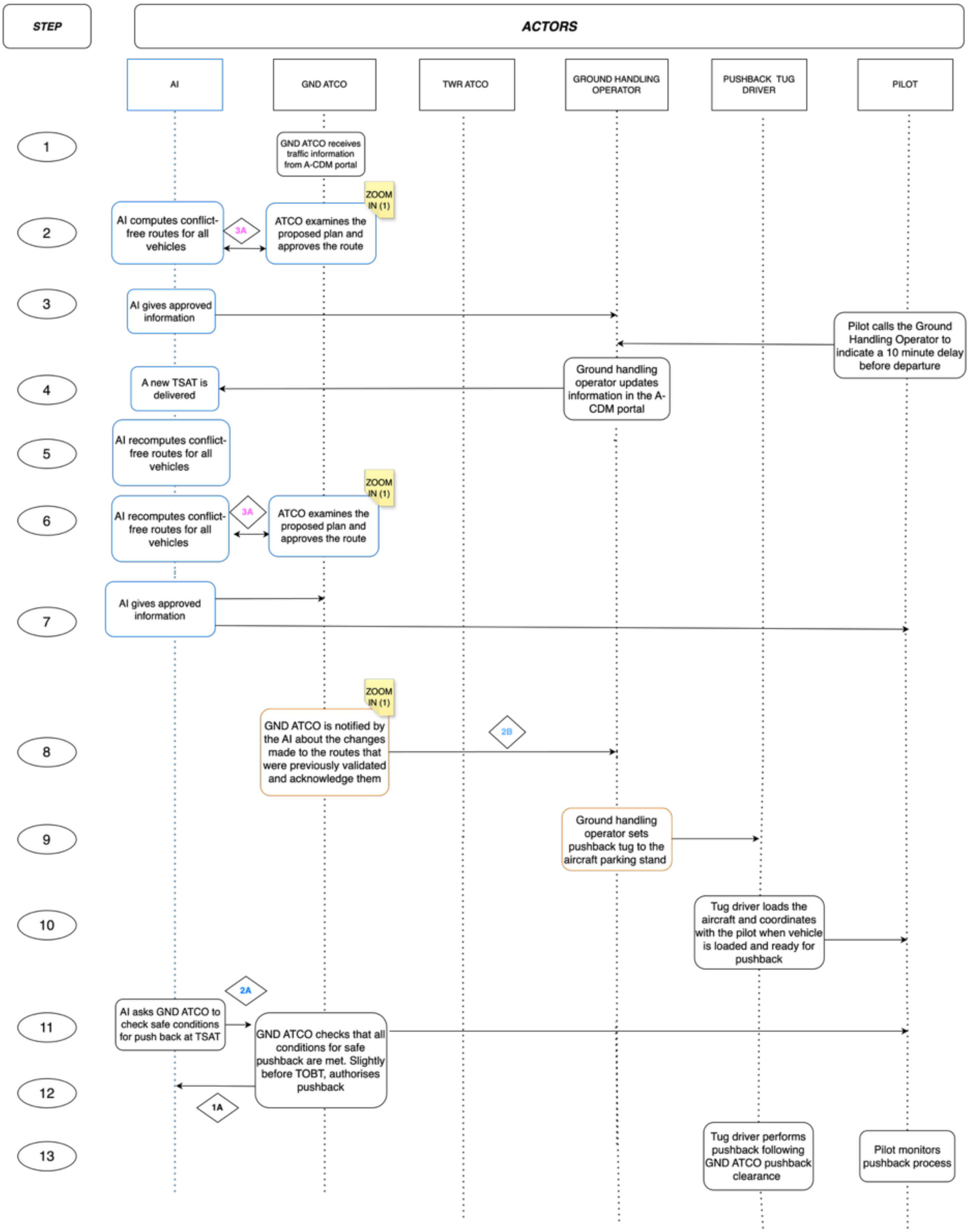

Figure 20: UC2 Normal departure with rescheduling sequence diagram (part 1)

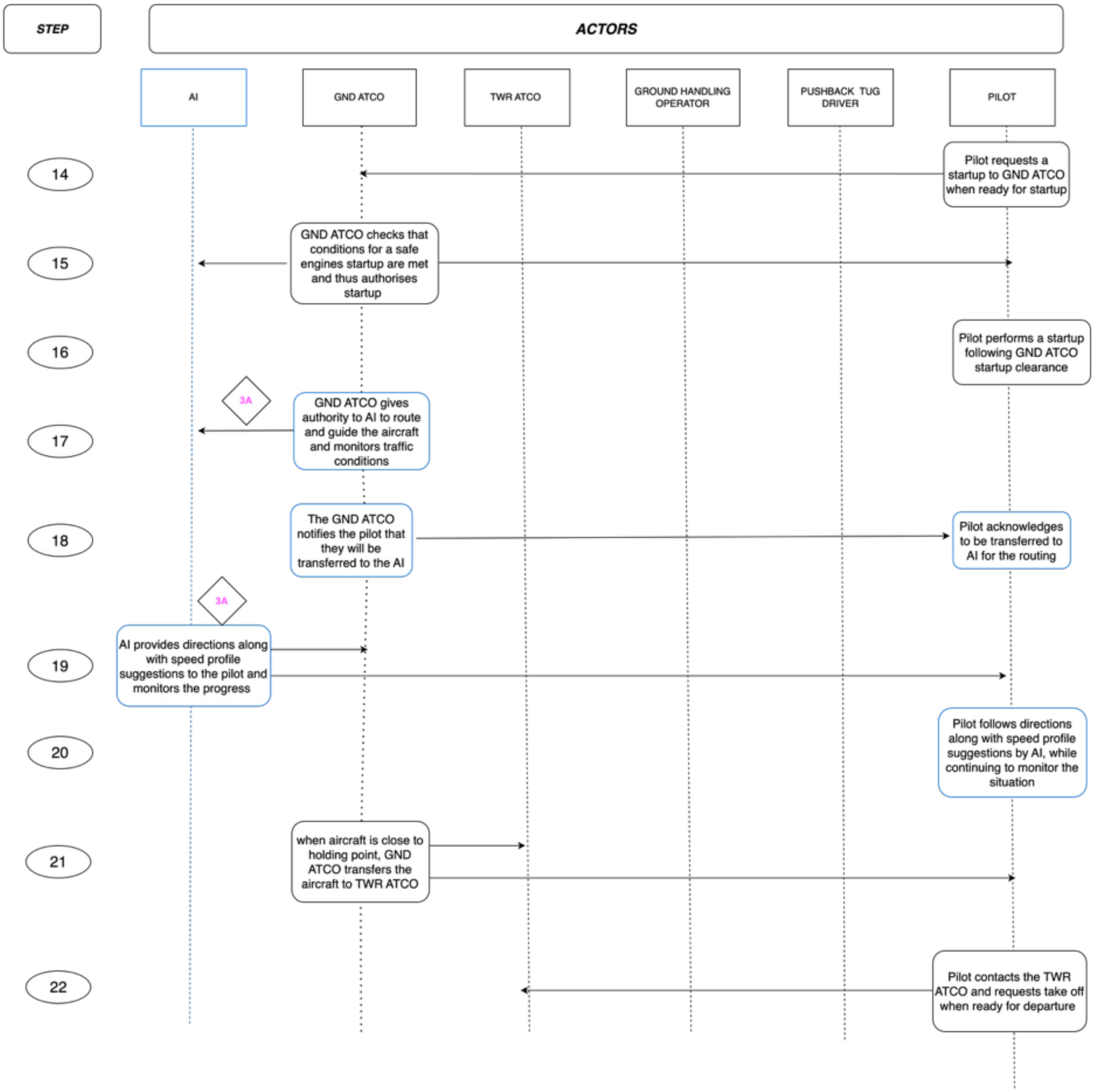

Figure 21: UC2 Normal departure with rescheduling sequence diagram (part 2)

3.2.2.3.3 Use case 3 (UC3) – Arriving traffic with occupied parking

In the same manner, the next use case, Figure 22, looks at an unexpected event for an arrival aircraft and the unavailability of its parking, the previous aircraft being late for departure. In this case, the interesting part to investigate would be the different potential solutions hard to evaluate for the AI to propose the best one without additional contextual and real time information from a human operator (expected occupancy time, impacts of parking's reallocation...). The AI shall highlight the parking issue it found automatically, specifying which aircraft are involved. Then the operator shall be able to input the desired strategy in the system so that AI can implement it, either slow down the inbound traffic or choose a remote holding position.

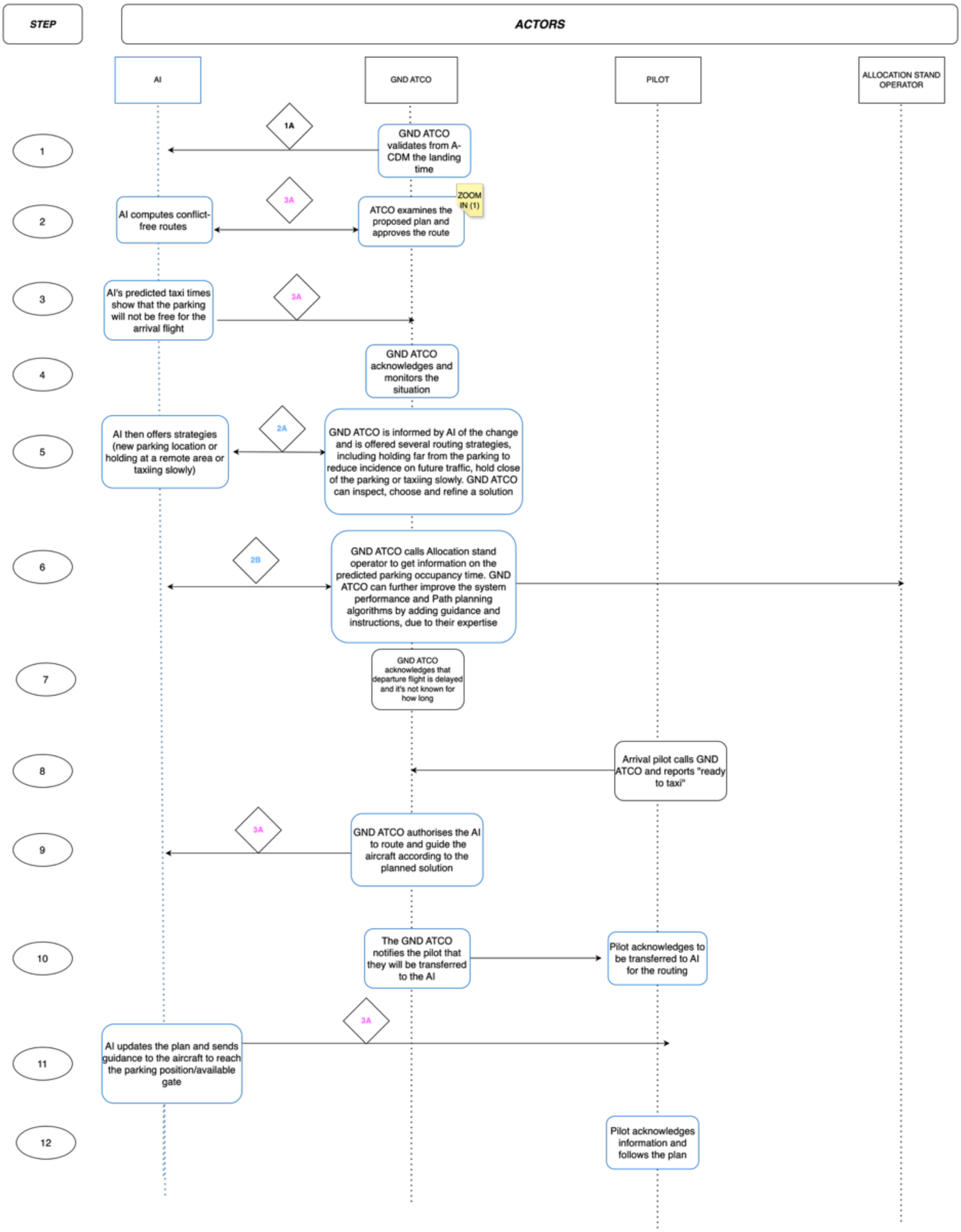

Figure 22: UC3 Arrival with occupied parking sequence diagram

3.2.2.3.4 Use case 4 (UC4) – High level taxi strategy tuning

This use case Figure 23 describes a situation in which case an operator can adjust the AI routing strategy to respect strictly or not the airport rules. For now, the only rules to be considered in the level of compliance of the proposed solution are the preferred taxiways directions in specific configurations. For instance, when the operator expects a lower traffic load in the next hour, the level of compliance to the rules can be relaxed to give more freedom to ASTAIR AI. The solutions found maybe more efficient even though the complexity of the situation increases, and it would potentially be more difficult for the operator to take over the operations. On the contrary, such a feature could be useful to prepare the human handover by setting a higher adherence to operational rules so that the operator get a more standard situation.

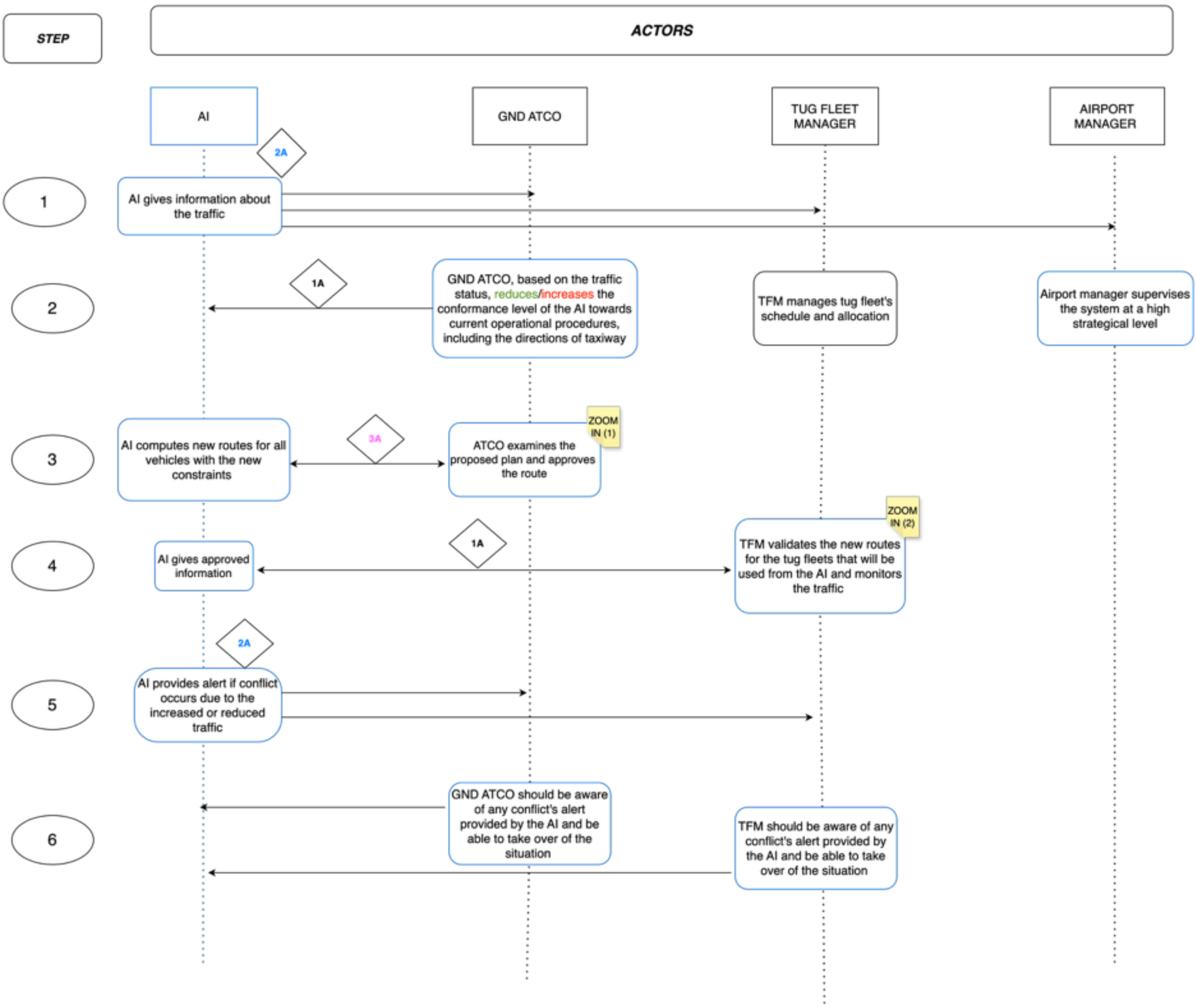

Figure 23: UC4 High level taxi strategy sequence diagram

3.2.2.3.5 Use case 5 (UC5) – Automation failure

Dealing with higher level of automation, a use case about automation failure is inevitable. Malfunctions could happen at two levels in ASTAIR concept, either the AI fails to compute a conflict free solution with the given planning, or the vehicles, that automatically follows the routing and speed clearances issued by AI, deviate from the computed solution.

Vehicles side failures should be handled through the A-SMGCS alerting system thanks to deviation or excessive speed alerts. In ASTAIR case, under speeding alerts should also be considered to monitor that vehicles are following the plan.

ASTAIR validation focused on the first case to analyse how the service level degradation could be perceived and managed by the human operator. In case of failing to find a conflict free solution with new traffic or constraints, the system would still be able to operate safe operations for a limited time, since the previously found solution covers a 20 minute time frame. If no solution is rapidly found, the system would not totally stop but would first revert to a simpler algorithm giving only locally optimal solutions, requiring more attention from the operator. This use case, Figure 24, addresses issues with operator's situation awareness on the available service level and information actually processed by AI.

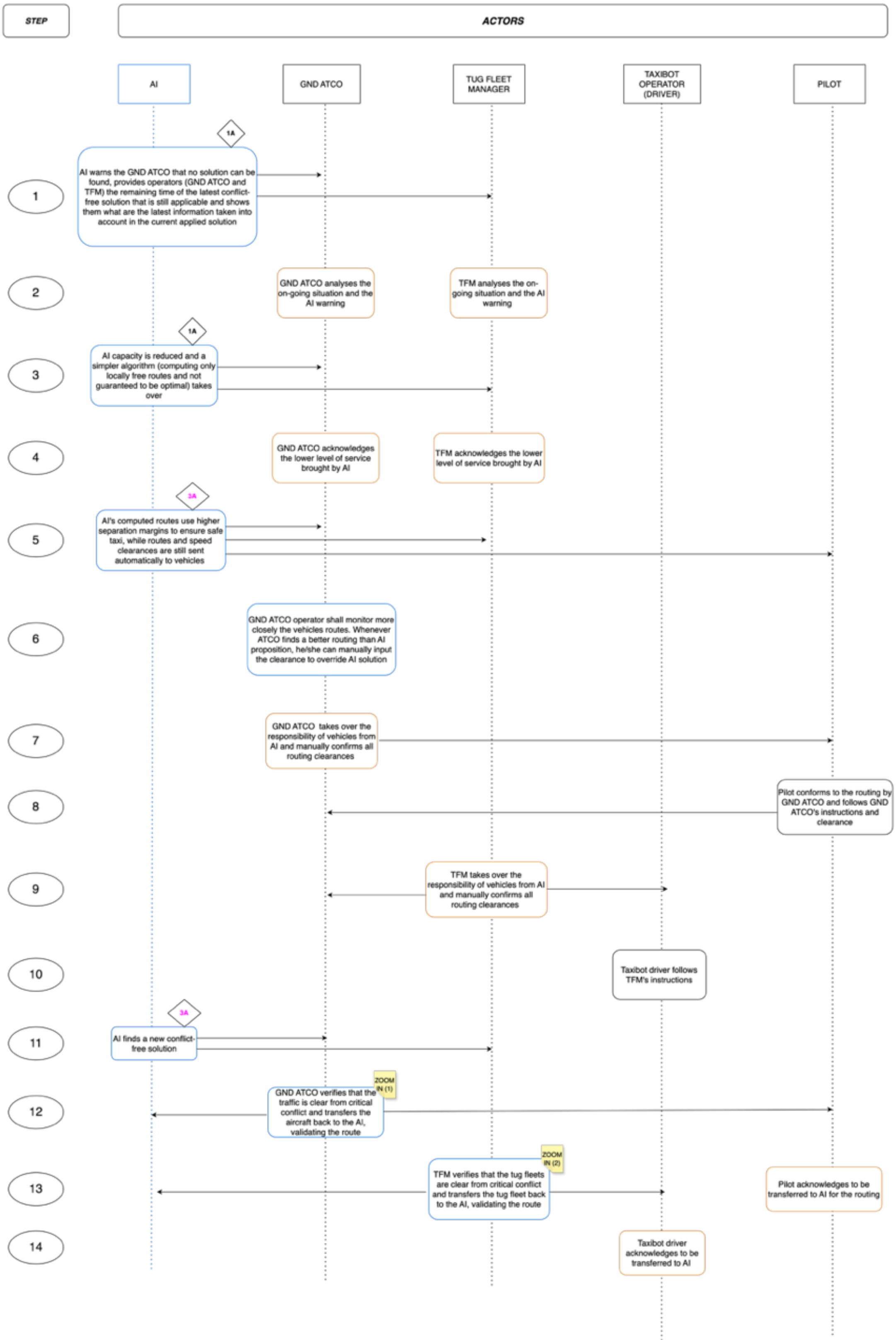

Figure 24: UC5 Automation failure sequence diagram

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3.2.2.3.6 Use case 6 (UC6) – Runway mode of operation modification

In case of runway mode of operation (RMO) modification, lots of aircraft and vehicles need to be re-routed in a short period of time. The point of interest here for ASTAIR concept is the different timings of operations compared to current operations. Indeed, today once the decision of RMO changed is acted the new routes computation can be quite rapid for a human operator but the implementation of these routings can be long due to the number of pilots to contact and the number of clearances to issue. On the contrary, ASTAIR AI may take a few minutes to compute the new routing and speed clearances, but the implementation of the solution would be quite fast thanks to automated digital communications. It is presented below in Figure 25.

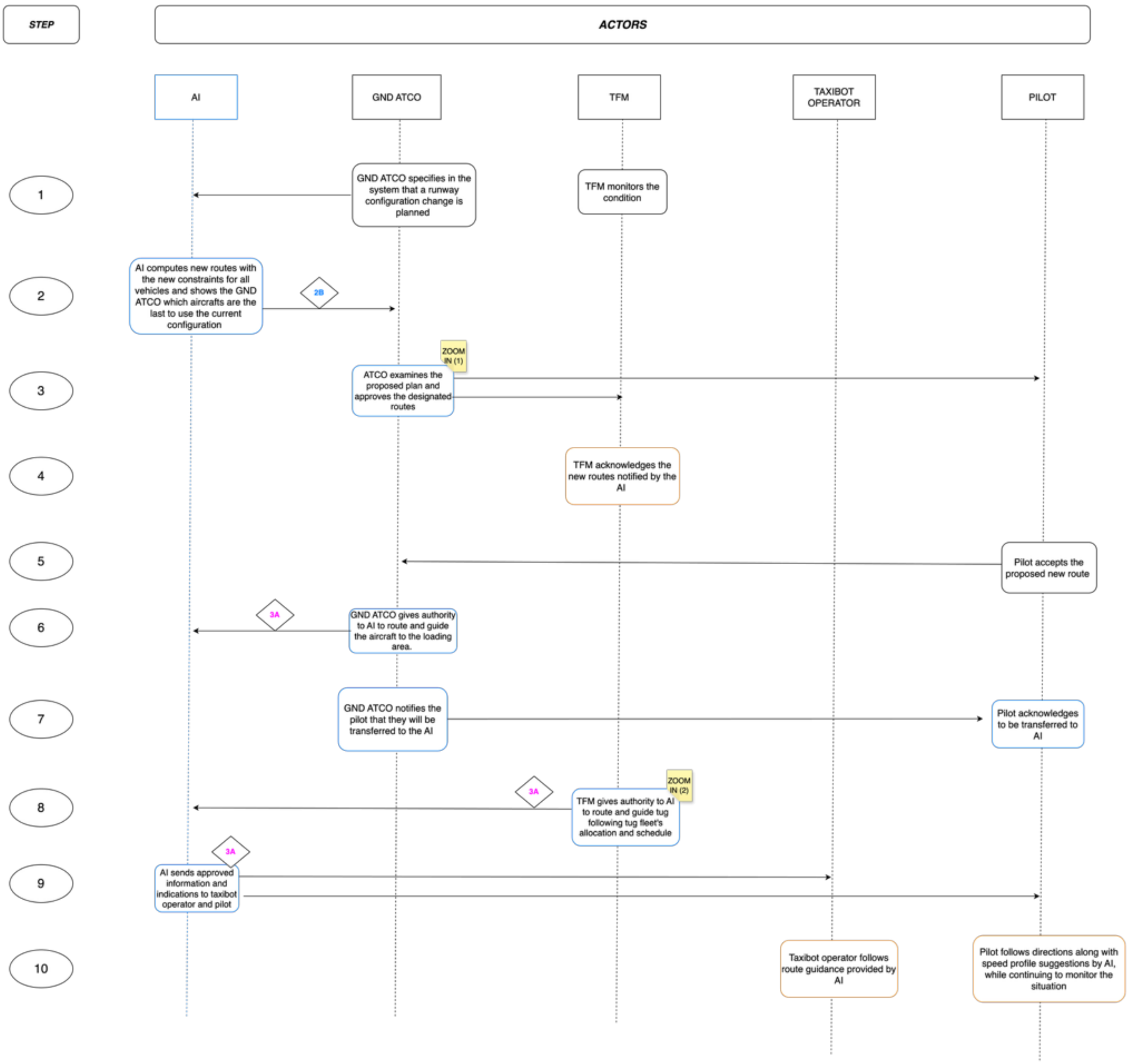

Figure 25: UC6 Runway mode of operation sequence diagram

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3.2.2.3.7 Use case 7 (UC7) – Departure remote holding (push and hold)

Another case for which ASTAIR concept would have an added value is the implementation of departure remote holding process, see Figure 26. The remote holding procedure is implemented by certain aircraft operators in response to air traffic control (ATC) notifications of anticipated significant take-off delays. Airport operator could also define remote holding procedure, in case of significant delays and when parking stand capacity issue exists. A remote holding at specific location may then be required. If de-icing area is used for holding, then the coordination with ATC and Airport operation may be required to cover all weather operations (AWO).

This allows flights to log an on-time departure and/or frees up a gate for other uses. The process involves ground positioning the aircraft to designated remote parking stands. In this location, the engines are turned off and ATC grants permission for engine restart and taxi to runway. The collaboration between the operator and AI would lead to optimal timing for restart and potentially to find holding locations that would not disturb other traffics.

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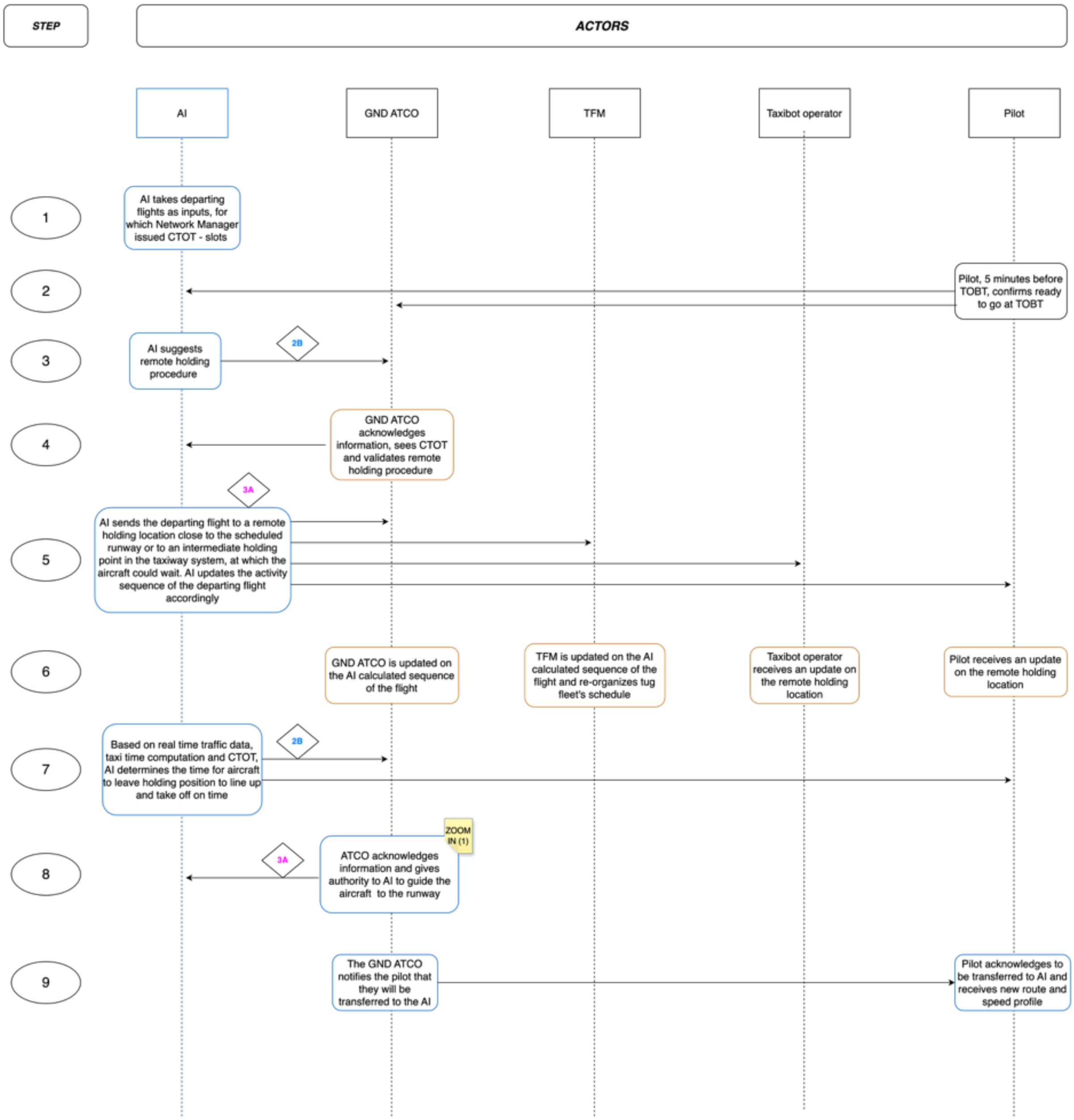

Figure 26: UC7 Departure with remote holding sequence diagram

3.2.2.3.8 Use case 8 (UC8) – Arriving flight with technical issue

This use case, Figure 27, describes a situation in which an arriving aircraft faces an emergency at landing and needs to reach quickly its parking stands or requiring inspection escort the aircraft to the parking. In that case, the human operator may want to rapidly gives a route to the aircraft and set it as a new constraint to ASTAIR AI for the routing of other aircraft and vehicles. This manually set route would reduce the potential solution space for ASTAIR AI since it becomes a constraint to respect.

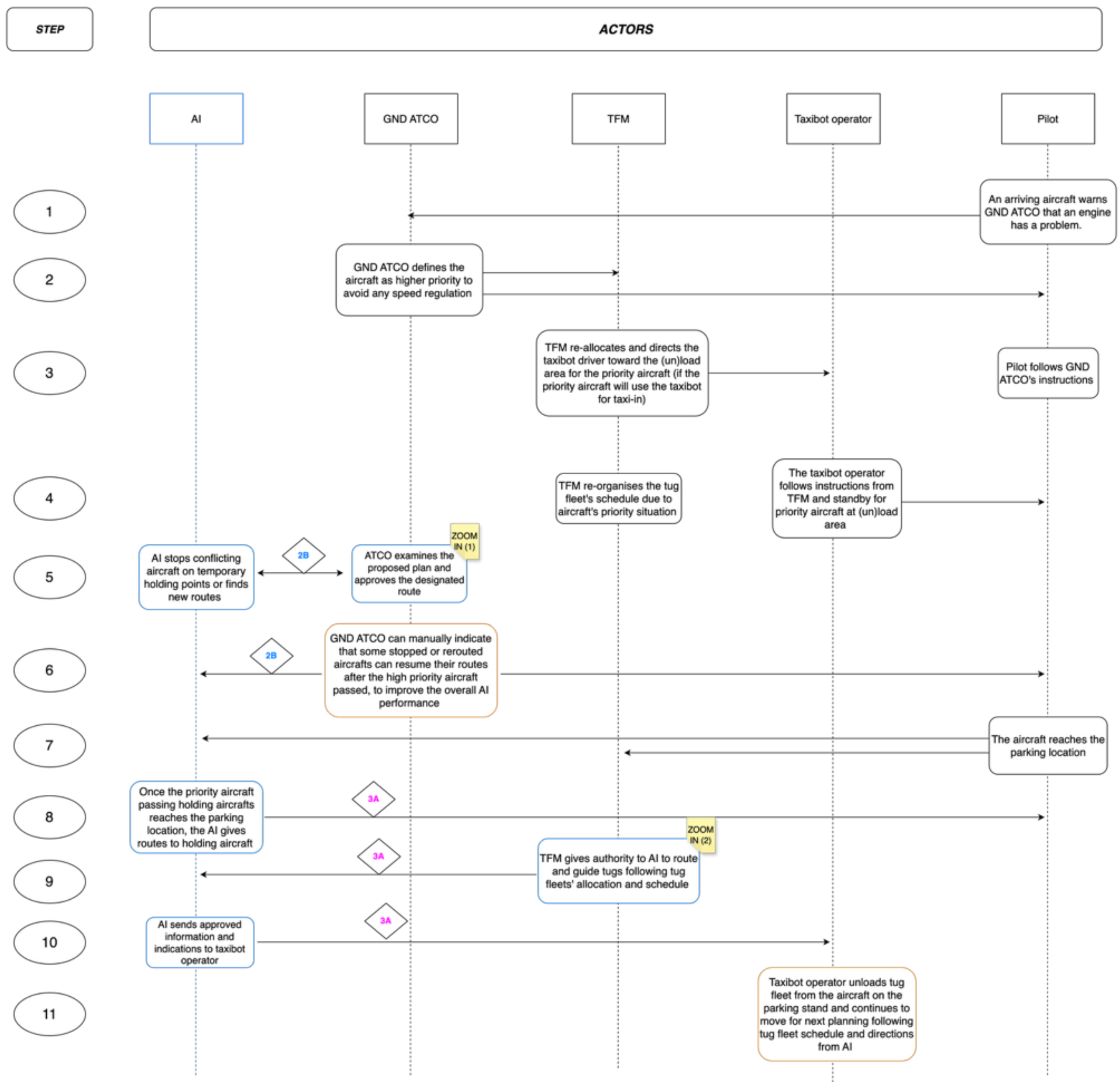

Figure 27: UC8 Arrival with technical issue sequence diagram

3.2.2.3.9 Use case 9 (UC9) – Departure flight with sick passenger

In this use case, Figure 28, a departure flight has started the normal procedure in ASTAIR solution, it is already taxiing and sometime before reaching the runway entry, the pilot calls ATC to request to go back to parking because of a sick passenger on board. Because AI may not be reactive enough, ATCO must then give manual instructions and guide the aircraft back to its stand. This will impact the traffic with potentially re-routing or stopping other aircraft on the way. Once the event is solved, the ATCO can give back authority to AI to guide aircraft that have been impacted.

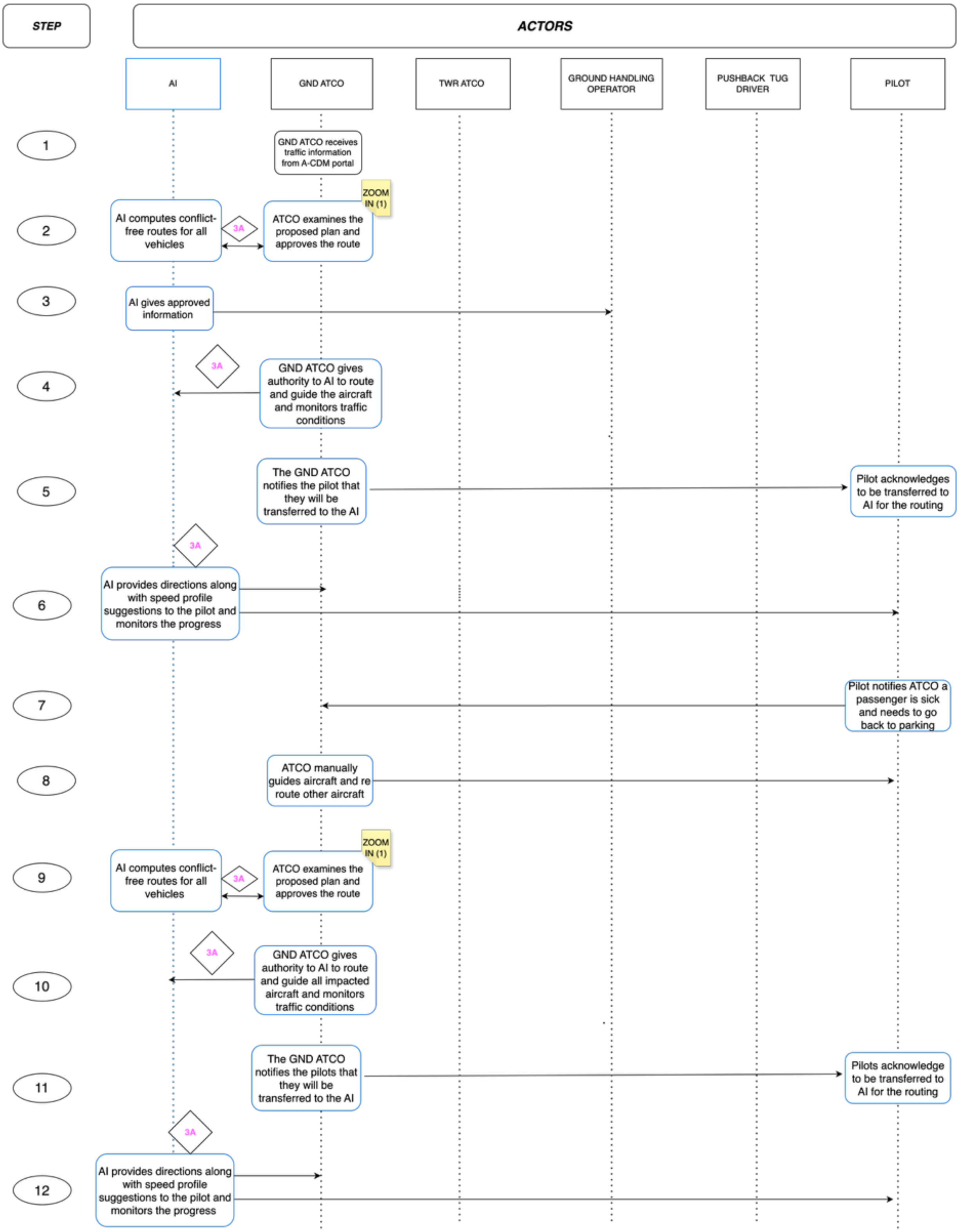

Figure 28 UC9 departure with sick passenger sequence diagram

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3.2.3 High level requirements

Operational requirements:

- The operator shall be able to visualise the future trajectories of all mobiles (aircrafts, vehicles such as Taxibots, tugs).

  Note: operator can be ATC operators, tug fleet managers or airport managers.

- The system shall have the autonomy to take care of routine tasks (calculation of conflict free routes, giving digital clearances to specific a/c, allocation of tugs etc.) to lower operator's workload.

- The operator shall be able to override the system clearances.

  Note: A system clearance, is a clearance taken by an AI agent

- The operator can use radio communications or datalink to override AI clearance.

- The routing service shall provide priority to human clearances in its computation.

- The system clearances shall follow standard traffic rules; it would facilitate acceptability by the operator and potential handover procedure in case of failure.

- The system shall be pre-compute potentially hazardous situations (conflicts or potential encounters) and show them to the operator for more careful monitoring. These alerts shall be prioritised based on the current traffic conditions and the system's traffic predictions.

- The operator shall be provided with information on which is the current surveillance information, and which information is based on the AI's traffic optimisation plans to support their situational awareness.

- All 4D trajectory traffic representations (current and ASTAIR optimisation plans) should be displayed on the current HMI (no additional screen).

  - Rationale: ASTAIR real time validations used 2 screens to differentiate real time and forecast traffic, the operators found it difficult to use.

- The ATC operator shall be provided with an A-SMGCS system including routing and airport support services in addition to ASTAIR future trajectories visualisation tools

- The Tug Fleet Management operator shall be provided with tug fleet agenda (see SESAR solution defined in AEON) in addition to ASTAIR future trajectories visualisation tools.

- The operator shall be able to implement airport, traffic or any operational constraints into the system.

  - Rationale: operator should always be able to override AI decisions; the most obvious way would be to give direct clearances over radio to pilots and drivers. However, it

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would be smoother if any AI routing decision could be edited partially to follow operator's objective.

- The operator shall be able to delegate the traffic control and monitoring to the AI on request.
- The operator shall be able to modify any mobile route by changing its speed.

Human Performance requirements:

- The operator shall be able to trust information they are provided with by the system.
    - Rationale: The operators need to be confident that the ASTAIR system and its functionalities are reliable and accurate to use them effectively, but the level to which the tools are assured needs to reflect this. This is reliant on recorded accuracy and perceived trust of the user. Trust can be increased by improving system transparency.
- The operators shall be able to understand and assimilate information from HMI elements introduced by the ASTAIR toolset.
    - Rationale: The ASTAIR concept will change the type of information that controllers must assimilate to have a clear traffic picture. In particular, the presence of AI optimisation plans functionality, and how this influences forward planning (and controllers' mental model), trajectories and conflict detection. As such, controllers must be able to determine, differentiate (e.g., prioritisation of conflicts) and understand the type of information they are looking at through the user interface and be able to maintain a safe level of situation awareness consistently.
- The controllers shall be able to maintain and build team (human-AI) situation awareness through live updates of any issued clearances by the AI.
    - Rationale: Whenever the system finds a better solution for already taxiing aircraft, the operator shall be warned if the trajectory is modified (and this shall happen as little as possible). If the optimisation only deals with speed profiles then no notification is required.
- The controller shall understand their roles and responsibilities and which aircraft they are responsible for (including maintaining separation) within their responsibility (and control) at all times, and which aircraft is the AI responsible for (aircrafts controlled by the AI – as displayed within the left strips column on the HMI). The controller shall be provided with a mean to distinguish the mobiles under his/her control and the one managed by AI
  Note: this can be done through different list in the display and different colours
- The operators' workload should not be increased when using the ASTAIR concept.
- The operators shall find that the workflow of tasks and communication with other parties (tug fleet manager, tower controller, etc.) is not degraded compared to today's operation. The operators shall be able to communicate with each other when necessary.
- The controllers shall be able to issue clearances and control a/c under the ASTAIR operations without a reduction in their situation awareness.
- The controllers shall actively control fewer aircrafts compared to current operations

Note: with ASTAIR concept, ATCOs role is shifting towards more supervisory role (as opposed to current “control role), due to the introduction of human-AI team and ASTAIR’s AI optimisation plan functionality.

- Controllers shall keep their aptitude to continue controlling in case of system failure.
  - Rationale: To use information appropriately the controllers should understand how the system is calculating displayed trajectories, what they consider (including high level understanding of algorithms) and therefore, this shall support their mental model when using this information and supports human-AI teaming.
  - Training shall take place to use the new system but also to keep the current qualifications in case of a system failure

Technical requirements:

- The system shall retrieve traffic information from operational data sources, such as A-CDM and A-SMGCS surveillance service to enhance the predictability of surface movements.

- The A-SMGCS system shall include routing and airport safety support services

- The system shall provide a mean to differentiate current surveillance data from AI’s traffic optimisation plans

  Note: this can be done through different list and colours

- The routing service shall provide 15 to 20 minutes of conflict-free trajectories on a time rolling horizon to ensure results are always available, based on the surveillance data and AI optimisation plans

- The system routing module shall avoid trajectories modification for vehicles already in movement. The routing service shall be proposing speed order to keep safe operations.
  - Rationale: Vehicles that have already started taxiing should better be managed in speed control rather than trajectory modification so that both ASTAIR operator and vehicle driver are not bothered.

- The AI assistance shall be able to issue digital clearances, trajectories and speed profiles to vehicles via CPDLC

- The routing clearances shall consider vehicles performance envelope/limitations.

- The system shall be capable of dynamic re-planning of taxi routes in case of non-nominal situations (unexpected disruptions or emergencies), while ensuring safety and minimal impact on traffic flow.

- The system shall warn the operator when AI assistant fails in specific task.

  Note: this requirement is linked to UC5

- The system shall warn the operator when vehicle deviates from cleared trajectory.

  Note: this requirement is already part of the A-SMGCS Airport Safety Support Service (ASSS) requirement but ASSS, route deviation alert shall be implemented to be able to implement the ASTAIR concept

- The system should provide contextual details, such as the priority level or sequencing order of aircraft, to help understand the automated clearances.

- The system should be able to uplink information and instructions to pilots by integrated cockpit avionics (e.g. Airport Moving Map).

- The system shall enable issuing of clearances only by one member of the human-AI team (the controller or the AI) and shall prevent issuance of clearances by two or more actors (AI, GND ATCO, TWR ATCO) into the same piece of ground movement area (prevent any simultaneous actions).

- The system performance (overall system performance (no lagging, refresh rate), conflict calculations/re-calculations, visualisation of trajectories (current and predicted)) shall support the operations and support operators' human performance.

3.2.4 Potential limitations, weaknesses and constraints

The concept of ASTAIR Project presents numerous advantages, such as increase efficiency and reduced human error due to over workload. However, it is also coming with a range of potential limitations, weaknesses and constraints that must be considered. Below is the analysis of these factors:

3.2.4.1 Technology

- Vehicles must be able to autonomously follow route and speed clearances. 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 (Autonomous Taxi, Take-Off and Landing (ATTOL) project).

- ASTAIR concept applies to A-CDM airports equipped with A-SMGCS or more generic to airport with surveillance data, digital clearance inputs and data sharing among stakeholders.

- Datalink / CPDLC communications shall be reliable and fast to exchange clearances.

- Integrating a new system with existing procedures and operations can be complex. The differences between their operations may lead confusion.

- High levels of automation are required. 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.

- Human–automation teaming raise difficulties. Collaborations between human operator and AI is a particularly challenging design aspect. 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. Study how to design interactions enabling cooperation between humans and AI is needed, 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, the researchers need 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.

- AI computation time / ability to handle operational constraints.

3.2.4.2 Regulation

The implementation of new system requires testing and certification from aviation regulator. To accomplish this, a considerable amount of time is required because these matters encompass the completeness of equipment, usage procedures, personnel involved, safety protocols, liability concern and many other factors that need to be considered. In addition, there may be a need for new regulations that can oversee the implementation of the system's use at airports.

Collaborations between human operator and AI in ASTAIR project, issue related to liability will be a concern for all parties involved. In order to address liability risk, regulation will act as a vital legal umbrella to creating safer operational landscape. The liability risk outlined in the Workshop report pertains to speed clearance/speed profile, higher levels of automation, and capacity increase, which have become primary concerns that raise several questions and doubts regarding the system that will be implemented in the ASTAIR project, such as:

- How far can we go with automation? Are the proposed levels of automation acceptable?
- What is the view from the regulator? Could there be certification issues?
- Is the human capable to take over at any point? Liability issue: in AI level 3A (the AI-based system performs decisions and actions that are overridable by the human) who is responsible in case of incident? the AI developer?

3.2.4.3 Human Factor

- Users Trust and Acceptance Issue

  One of the key factors in the human-automation relationship is the level of trust a person has in automation. In the journal by Doroteja Timotic and Fedja Netjasov titled "Automation in Air Traffic Control: Trust, Teamwork, Resilience, Safety "[21], it is quoted Individual differences should be taken into account in analyzing the human-automation relationship.

  Although the journal focuses solely on Air Traffic Control (ATC), it can also be concluded that almost every job at the airport, especially those related to flight safety, personality traits may have a great influence on operators' reasoning, making decisions and actions in situations of different demands and complexity. Their acceptance of new tools and technology may be determined depending on what type of person they are.

  Several factors that may influence operators' trust and acceptance in the automation systems offered by ASTAIR, including:

  - Automation characteristic, such as reliability and transparency

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  - Task complexity and human-automation teamwork
  - Lack of information about the system
  - Current and historical automations' abilities
  - The experience of the operator with similar system

- Using higher levels of automation, ground operations could shift the roles of humans toward supervisors. Reliable automation may affect decreasing of human stress and fatigue which further will lead to reduced workload. However, allowing automation to perform more tasks within the system may result in operators' loss of situational awareness and skill degradation (Parasurman et al, 1993).[21]

- Training requirement

  Based on the explanation regarding the lack of understanding about the system causing personnel's distrust in using the technology, it can be concluded that the need for training related to the systems used is very important.

  To determine what training is needed and the level of training that can be conducted for each personnel, a Training Needs Analysis (TNA) is required. To complete the TNA, users may need to Manage a project, Locate and review relevant information, Locate or develop a Job Task Analysis (JTA), Prepare and use different methods to gather data (interviews, surveys, etc), Review the data and extract essential information and Present and discuss results with managers and stakeholders[22].

The need for this training depends on several factors, including the regulations currently in use, the technology currently being developed and will be used (its urgency), the availability of experts or instructors, the availability of training providers, and their facilities (such as curriculum/syllabus and training equipment).

Concerning the acceptability of the concept, transforming operator work into supervisory work requires a high level of confidence in AI and good communication between the operator and the system. Human-machine interfaces and interactions must be carefully designed to represent automation decisions and intentions in one hand, and AI must be capable to take in various constraints set by the operator.

Finally, the main impediments that has been reported in the various ASTAIR workshops concerns liability. Taking full control on the taxi phase of aircraft gives the full responsibility of the vehicles to airport managers. In order to ensure conflict free routing, taxi speed regulations are mandatory. If these regulations are transformed in timed meeting points given to a/c pilots, i.e. giving clearances with waypoints at given time, the movement in between waypoints is not constrained and conflicts cannot be avoided. Nevertheless, some mitigation solutions can be explored. For instance, for aircraft towed by Taxibots, the tug driver, who is used to the airport layout, could be responsible for the navigation or the airport could propose automated follow-me car that would not only give directions but could also manage the speed of the convoy.

3.2.4.4 Economic

- High initial investment

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Implementing automation technology involves significant upfront costs for research, development, installation, and maintenance of equipment.

- Training costs

  In addition to equipment, the training costs for each personnel must also be a concern. This is because to implement the ASTAIR concept, it is necessary to have competent and professional aviation personnel involved in the use of tools and maintenance needs.

3.2.4.5 Environment

Automation in ASTAIR concept shall adapt to airports that have varying aerodrome layout, signage and ground marking.

3.3 Expected performance outcome

The main expected performance outcome in the ASTAIR can manage and perform engine-off and conventional airport surface movement operations at a major European airport by designing a seamless partnership between AI. The following main performance outcomes are expected [17]:

- **Environment:** Beyond engine-off taxiing, ASTAIR will move towards more sustainable operations (noise, emissions). Optimised operations due to improved route planning contribute to the optimisation of fuel-burn and therefore to reduced CO2 emissions per flight. Average taxiing duration is also expected to be reduced, having a positive impact on fuel efficiency. As such, ASTAIR will make its contribution to establishing Europe as the most environmental-friendly continent to fly in the world. ASTAIR aims to reduce CO_2 and NOx emissions during ground operations, particularly through the use of zero-emission propulsion technologies This directly supports the SRIA ambition to achieve climate neutrality in European aviation by 2050
- **Punctuality:** ASTAIR is expected to have a positive influence on punctuality of departure flights through increased level of automation, leading in turn to more efficient and more predictable ground operations. In addition, integrated ground movement management and coordination with ATC aligns with the MAWP objective to improve the resilience and fluidity of airport operations.
- **Capacity**: ASTAIR will have a positive contribution on operational efficiency while ensuring a high quality of control. Increased level of automation will reduce controller (end-user) workload and increase capacity on the ground, as automated functions work regardless of traffic load and complexity. With automation support & virtualisation it is expected to have scalable capacity at the airport.
- **Safety**: Automation level introduced by ASTAIR (at minimum, level 2B AI - machine performs a function / Human monitors) is expected to have a positive impact on safety. Human errors are expected to be reduced or eliminated, as the computer is much faster and more accurate that the human brain. As in the future humans will work close to the capacity limit, automation of tasks will contribute to reducing stress-related accidents. Some new alerts will be added to the A-SMGCS Airport Safety Support Service to improve Safety.
- **Human Performance**: If automation is a reliable source for more capacity and efficiency, the importance of human factors and ergonomics in system design focusing on automation is

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prominent for increasing confidence in technology. ASTAIR will adopt a human-centric approach and user-centred design, supported by algorithms for efficient and conflict-free route of aircraft, tugs and vehicles. Coupled with strategies to deal with human cognitive demand, ASTAIR will bring a significant contribution to human performance. ASTAIR integrates AI to automate ground operations while maintaining effective human-machine collaboration. This addresses the SRIA objective of ensuring that technological solutions remain human-centric

- **Security**: ASTAIR will identify the potential risks deriving from having a more interconnected and automated ATM system such as component malfunctions or malicious interference; an increased level of automation generally means that extra care should be taken in order to prevent unauthorised intervention. The introduction of automation will need to be carefully shielded from unwanted external interference.

Based on the above, the following Key Performance Indicators are expected to be impacted by ASTAIR concept:

- Liability,
- Cost-efficiency (CEF)
- Security (SEC)
- Fuel efficiency,
- Safety (SAF),
- Environment (ENV; sustainability),
- Capacity (CAP),
- Human Performance (HP): workload, situational awareness, teamwork

The related KPAs and KPIs are described in ASTAIR ERP [24] and ERR [25].

3.4 Key assumptions

As explained in 3.2.3, ASTAIR solution targets airport implementing A-CDM and A-SMGCS (routing service a minima), which limits the scope of airports.

In order to be efficient, ASTAIR concept also depends on the possibility to have reliable digital communications with the controlled vehicles. Indeed, the clearances computed by ASTAIR AI need to be sent electronically to the vehicle.

In addition, another key enabler to the concept is vehicles able to follow a routing clearance with speed profile. Even though several solutions exist (Taxibot, autonomous follow-me cars, auto-taxi aircraft), the resilience of the Multi Agent System (MAS) towards deviation from plan shall be evaluated as well as the impact on airport capacity. Measuring the tolerance margins that the MAS is able to cope with will allow to estimate the precision required for the vehicles in terms of position and speed guidance without impacting the airport capacity.

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4 Proposed SESAR solutions

- Solution Title: **Autonomous Taxi Management**
- Solution Definition:

The solution aims at improving predictability, safety and efficiency on large airports implementing A-CDM and equipped with A-SMGCS, as it would upgrade the guidance service to make it more autonomous. The solution will consider 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. Previous SESAR solution 'Ecological routing with speed profiles' can forecast 20 minutes of vehicles trajectories, deconflicted using speed regulations. The solution centralizes information from different stakeholders to feed the routing computation and outputs relevant results according to stakeholders' roles. It will provide routing information to ATCO and gives clearances with speed profiles to aircraft and tow tugs; it will also propose tow tugs allocation to the Tug Fleet Manager. All these data will be updated in real time to adapt to the operational events.

Concerning a departure flight, A-CDM will be the entry point to potentially modify TOBT up to 5 minutes before the initial TOBT (conflict free routes computation can take up to 5 minutes) and it is delivered to TWR control in order to compute the departure sequence. On the other hand, this SESAR Solution 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). this SESAR Solution 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 computed by AI, the human operator will have the possibility to specify various constraints or input new information to AI to facilitate the ground movements and handle specific operational events.

The solution involves computing conflict-free routes for ground vehicles through effective collaboration between human operators and AI systems. Conflicts are resolved by adjusting vehicle speeds, and the clearances, routes, and speeds are electronically transmitted to each vehicle. A key enabler for this approach is ensuring that vehicles can precisely follow the assigned routes and speed orders. This can be implemented using dispatch tow tugs, autonomous taxiing aircraft or automated follow-me cars, all these systems being currently under development.

The principal difference with current operations is that ASTAIR solution proposes the ground ATCO to integrate incoming in advance in order to build a mental image of the situation in the next minutes instead of reacting to pilots requests. In order to help the ATCO understand the plan the AI has computed and facilitate trajectories integration, ASTAIR proposes an additional software layer to analyse results provided by AI. It consists first of an analysis of each vehicle trajectory to detect anormal speed up or down to detect regulations applied for deconfliction and in a second step, all trajectories are analysed altogether to detect potentially conflicting situations. Actually, even though all trajectories computed by the multi agent system are deconflicted via speed control in theory, it could happen that some crossings lead to close-call, several aircraft coming in the same intersection in a short period of time. These situations, once detected, shall be displayed during future trajectories integration and on the real time radar image as a reminder to the supervisor to check that there is no safety issue. This process of trajectories integration in advance can also be applied to the Tug Fleet Manager. Indeed, the TFM could supervise empty tugs movements in the same manner ground ATCO deals with aircraft and tugs coupled to aircraft.

- Solution Description

Ground ATC routing clearances during normal operations are repetitive and require a lot of radio-communication bandwidth. At the same time, new technologies are emerging to manage precisely vehicles' movement during taxi phase, and it is possible to compute in advance smooth and conflict-free vehicles trajectories on an airport thanks to speed control. Increasing the level of automation through an AI capable of planning conflict-free trajectories and managing routine movements autonomously on behalf of the operator could enhance the general predictability of airport turnaround operations and reduce ATCO workload, thereby increasing safety.

The solution aims at improving punctuality, safety and efficiency on large airports by providing automatic guidance to aircraft and tugs in the movement area, from pushback to runway line-up and from runway vacated to parking gate. The solution targets airports equipped with A-CDM (or any solution to provide flights schedules and data) and A-SMGCS with Surveillance and Routing services. Each stakeholder accesses a centralised tool that gathers all information to plan routing and tugs allocation. Then, using previous SESAR solution 'Ecological routing with speed profiles' the solution regularly forecast trajectories for all vehicles for the next 20 minutes that are deconflicted with speed regulations. The AI solution is presented on A-SMGCS screen, and the clearances can be transferred electronically to the vehicles, in collaboration with human operators. The solution also provides interfaces designed to facilitate the management of operational events and the supervision of the automated processes. The solution can also be integrated with SESAR solution 'Tug Fleet Manager' to handle tugs movements as well.

Fast time simulations did not show any downgrade in airport capacity. Real time simulations validated the operational feasibility; automation of routine tasks has been welcomed by users as it reduces the workload and radio usage. However, the integration of future traffic in current situation screen still needs work. In terms of benefits, smoother traffic means less fuel consumption and noxious emissions and better predictability reduce waiting times and queues at runway thresholds. Speed management enhances punctuality, but the vehicles shall be able to comply.

Any continuation on this solution shall further explore human automation/AI teaming when the automation fails. The validation shall also include pilots and drivers. Refining conflict resolution mechanisms and safety nets for ground controllers to handle non-nominal situations effectively is also needed. It also has to be noted that this level of AI automation lacks development standards and regulations.

Tags:

- Benefits: Operational efficiency, Punctuality, Safety, Human performance, Sustainability
- Stakeholders: ANSP, AO

- Nature: ATM solution
- Initial maturity TRL0
- Target maturity TRL1
- Link to previous SESAR Solutions:
    - Management of non-autonomous engine-off taxiing operations by Tug Fleet Manager (this solution uses the concept)
    - Ecological routing with speed profiles (this solution is a direct continuation and will enhance the previous solution)

5 Plan for next R&I phase

The future R&I steps following this work would typically look into:

- **Validation**
    - **Key Technologies**: Testing the feasibility of proposed autonomous taxiing solutions (e.g., tugs, onboard systems) under operational conditions. This includes validating ecological routing algorithms and speed regulation systems.
    - **Other end users / effected stakeholders' involvement in the validations (RTS and workshops)**, such as pilots, tug fleet manager, airlines, tower controller.

- **Integration with Existing Systems**: Continuing the development of integration between ASTAIR and current airport systems such as A-CDM and A-SMGCS to ensure seamless operations. Better integration of inspecting tools into existing A-SMGCS.
- **Human-Automation Teaming**:
    - Exploring advanced collaboration between human operators and automated systems to ensure safety and manage complex airport environments.
    - Handover when automation fails, i.e. degraded automation (keep lower level of automation (L1A-L2A) + recommendation tools).
    - Faster computation times exploring mixed AI such as surrogate models to answer quickly any operator request with approximated solutions while the actual AI finishes recomputations.
    - Using machine learning based AI to facilitate the integration of ASTAIR AI. For instance, use historical data to better estimate ETA and AOBT so that ASTAIR AI gets reliable inputs. Another use case could be to learn ground tower ATCOs collaboration habits in the departure sequence management to avoid manual inputs overriding ASTAIR AI results.

- **Operational and Safety Enhancements**: Refining conflict resolution mechanisms and safety nets for ground controllers to handle non-nominal situations effectively.

According to the vision outlined in the ATM Master Plan [30] and the EASA AI Roadmap[29], human operators in air traffic systems will increasingly delegate tasks to automated systems, creating a collaborative human-machine team. Thus, the next research should evaluate:

- The effects of technological advancements, particularly changes in automation levels and the shift from executive to supervisory roles, on the nature and frequency of operator interventions, required skills, and overall performance, including the impact on fatigue.
- Potential safety risks/hazards associated with the evolving role of human operators, such as the cognitive demands of supervisory tasks and how they might affect performance and safety.

- **Liability:**

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- Promote a clearer definition of the ATCO's monitoring tasks, especially when the ConOps assumes that they should receive inputs that have no immediate impact on their sequence diagram.
- Ensure better human oversight, including through explainable operations (by design and by default) and a transparency policy involving instructions, manuals and training.
- "Provide a clear definition of the conditions under which authority is delegated to or from the AI for each actor involved and assess the resulting impact of such delegation on the subsequent forms of Human-AI Interaction (HAI) with other actors interacting with the system.
- Promote a clearer definition of the TFM operative profile, bearing in mind the margin of action defined by Delegated Regulation (EU) 20/2025.

6 References

6.1 Applicable documents

This concept outline complies with the requirements set out in the following documents:

Content integration

[1] ASTAIR D1.1 State of the art

Content development

[2] ASTAIR D1.2 Workshop reports

Validation

[3] ASTAIR D5.1 Exploratory Research Plan

Project and programme management

[4] [101114684] ASTAIR Grant Agreement, 31/05/2023

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[8] Skybrary taxiing definition: https://skybrary.aero/articles/taxiing

[9] Sustainable Taxi Operations: Concept of Operations & Industry Guidance, Edition 1.0

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[24] D5.1 ASTAIR DES HE SESAR ERP_v.01.00, 19 September 2024

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[29] EASA Artificial Intelligence Roadmap 2.0. Available online: https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-roadmap-20

[30]SESAR ATM Masterplan. Available online: https://www.sesarju.eu/masterplan

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7 Appendices

7.1 Concept implementation example

7.1.1 Proposed working position setup

For the real time validation exercices, the ground ATCO was in charge of apron and ground control, the tower controller was simulated. The working position was composed of a 180° out of the window view, completed with two 27 inches screens displaying on the left the A-SMGCS radar image and on the right the HMIs dedicated to AI supervision (Figure 29).

Figure 29: Real time validation physical setup

Even though most of the clearances were digitally sent via Datalink, the controller still had a radio communication with the pilots for first contact and emergency messages if needed.

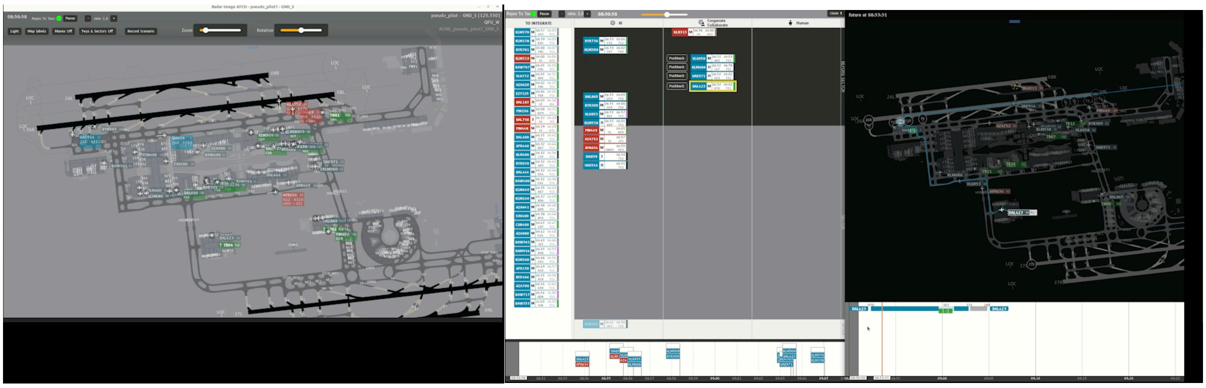

Figure 30: Close up on HMIs

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As shown on Figure 30, the A-SMGCS radar image is quite classic, with a stripless display of radar tracks. In the middle, the Supervision HMI proposes 3 columns to assign the flight, via their strips, either to AI, Human or collaboration. Finally on the right, the inspection interface is a radar image that allows the ATCO to explore the computed trajectories for each traffic in the future. More details on these HMIs can be found in D3.1

7.1.2 Trajectory integration process

The principal difference with current operations is that ASTAIR solution proposes the ground ATCO to integrate incoming in advance in order to build a mental image of the situation in the next minutes instead of reacting to pilots requests. Below is a step by step explanation of the process.

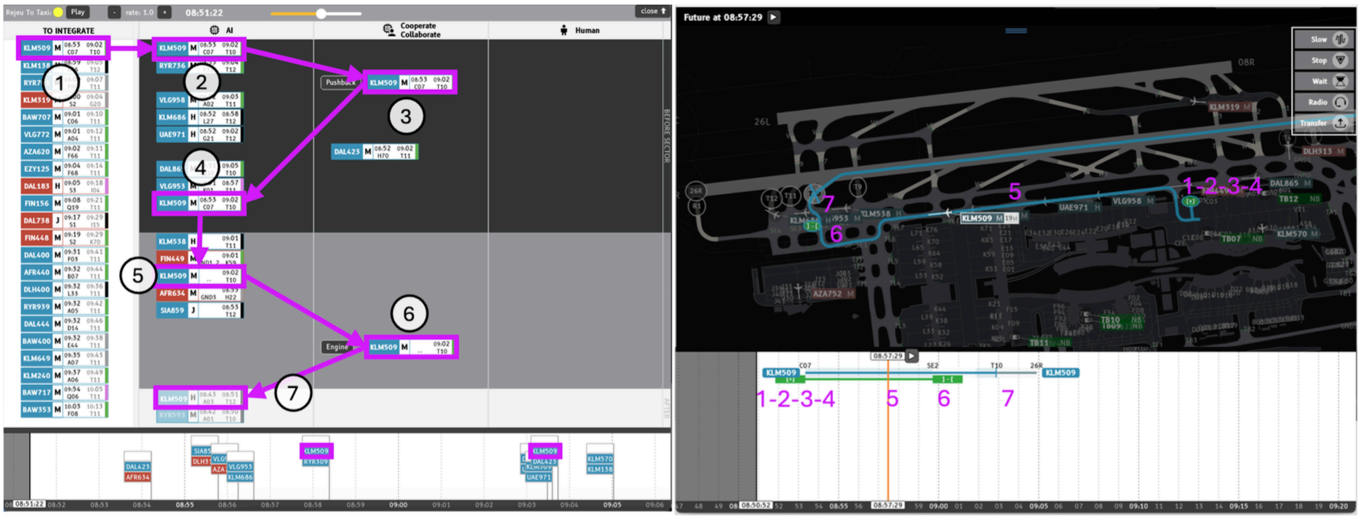

Figure 31: Trajectory integration

On the left, all incoming traffic is listed with electronic strips sorted by movement time. KLM509 is a departing aircraft in the supervision interface (left) and inspection interface (right):

1) A few minutes before TSAT, or when the pilots calls to confirm TSAT, the ATCO can select the strip and look at the AI computed trajectory in the inspection interface. The ATCO can use the slider to go back and forth in time and observe the aircraft moving along its trajectory together with the predictions of other traffic moving around it.
2) In this particular case, no traffic is interacting with KLM509, the ATCO decides it is safe to give full authority to AI to manage it. The strip is then integrated to AI column and digital clearances will be automatically sent to the aircraft on due time,
3) Shortly before TSAT, the strip transitions automatically to the Human-AI collaboration column since startup need to be approved by the controller,
4) Once ATCO has visually checked that pushback can be safely executed, it is approved and the strip is automatically moved back to AI column,
5) When the aircraft actually starts moving the strip moves down to the taxiing area,

6) Then when AI has computed that the suitable time up for engine start up procedure is reached, the strip transitions again to the collaboration column so that ATCO can check that engine startups is safe,
7) Finally aircraft is transferred to the runway controller and the strip disappear slowly.

7.1.3 Interpretation layer and cross-checks

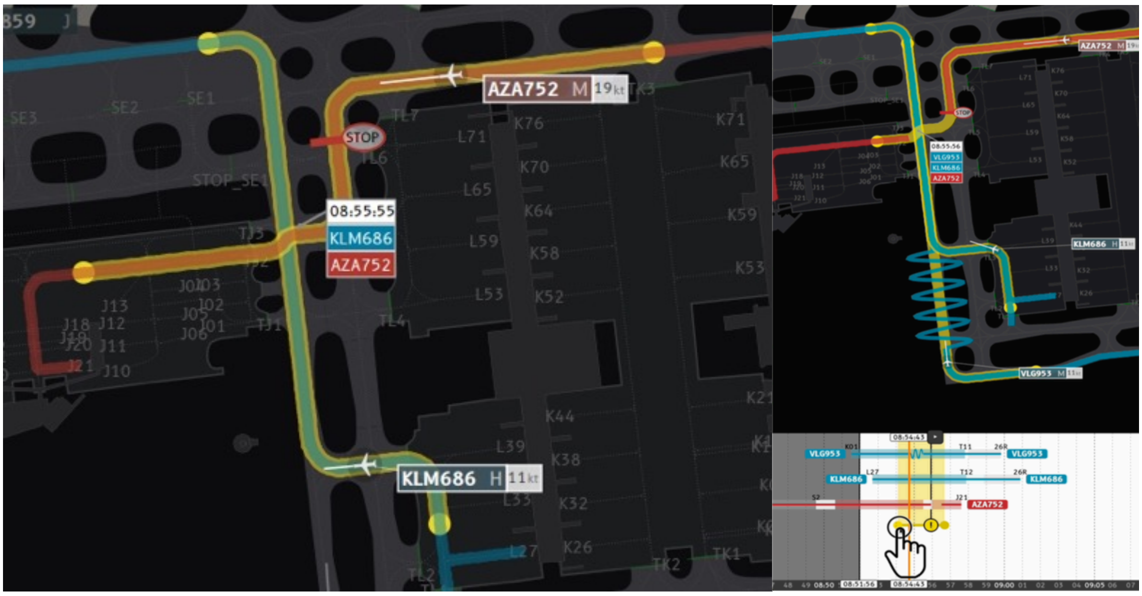

Figure 32: Cross check situation

On Figure 32 left part, we can see that a close intersection of AZA752 and KLM686 route has been detected and AI has decided to stop AZA752 to give way to KLM686. The yellow highlighted portions of trajectories show the duration during which a warning will be raised to the ATCO in real time. A warning typically means that the strips of the aircraft involved in the situation will automatically transition to the Human AI collaboration column of the supervision HMI when the ATCO shall check that the plan is correctly followed by both aircraft.

It can be noted that AZA752 is going to a full stop instead of only slowing down because it will actually give way to 2 departure aircraft, VLG 953 is following close behind KLM686. In addition, the right part of Figure 32 also shows that AI chose to reduce VLG953 speed to give way to KLM686 on its right (the wavy part of the blue trajectory show where the slow down shall happen). This way the ATCO can understand how AI decided to handle the potential conflicts.

7.1.4 AI routes overriding

At anytime, the easiest way for the ATCO to override AI automatic guidance is simply by giving a clearance to the pilot directly over radio. The ATCO can also manually modify the trajectory on the radar image by simple drag and drop, this would result in a new digital clearance emission. As it is shown on the image below, it has also been anticipated that the ATCO could manipulate the trajectory with a finer grain and specific action to be directly drawn on the trajectory. Nevertheless, these features have not been tested in the real time validation exercices.

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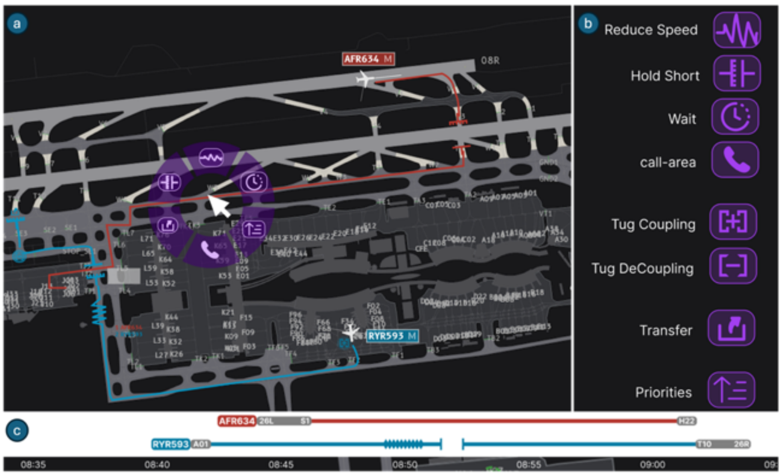

Figure 33: manual route edition

7.1.5 Tug Fleet Manager integration

The Tug Fleet Manager solution, designed and developed in AEON (and proposed as a SESAR ATM Solution) could benefit from the ASTAIR solution as well. In the same manner, the A-SMGCS radar image can be coupled with ASTAIR supervision HMI, the Tug Fleet Management interface can be used to select an empty tug and analyse its AI computed trajectory, Figure 34 illustrates this.

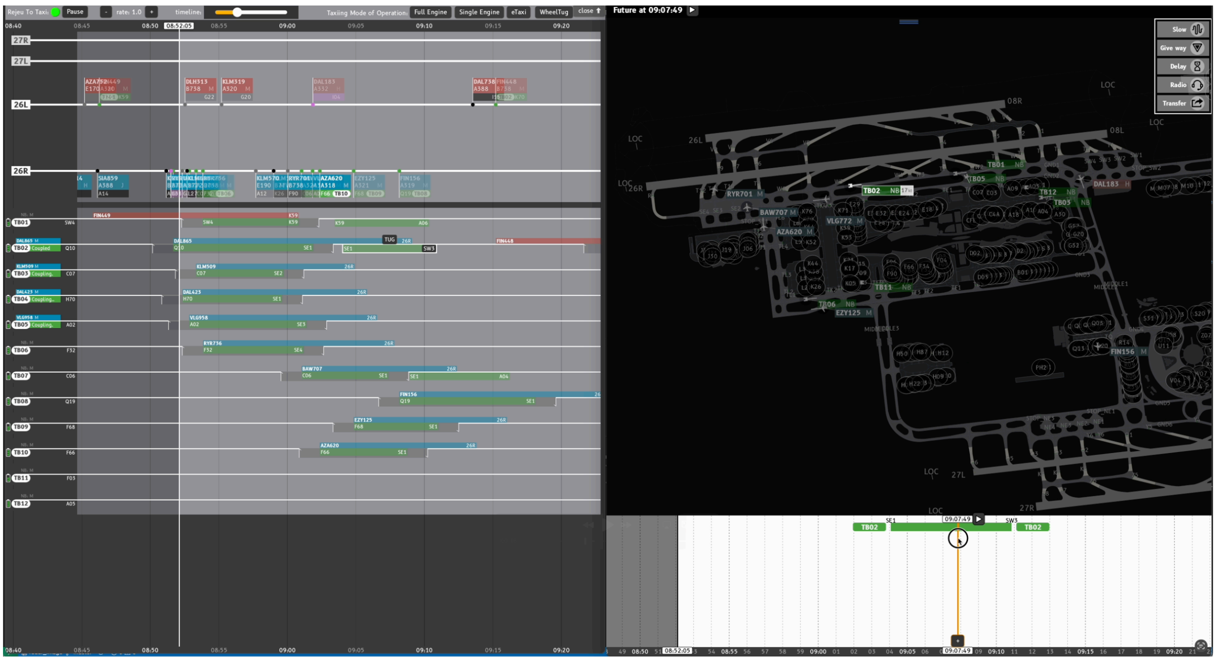

Figure 34: Tug Fleet Manager with inspection HMI

- Left is the TFM HMI :

- The first 4 lines shows the incoming traffic sorted by runways (blue are departure and red arrival)
- Under the runways we have one line per Taxibot showing their mission (green bars show empty tug movement, red/green or blue/green are tug towing an a/c). Not shown here but the AI can also plan for Taxibot charging period in between missions.
- These mission are initialised with AI plan but can be modified manually by the operator according to operational events.

- Right is ASTAIR 'future radar image', i.e. the radar image showing the future as it has been computed by AI. The operator can select a tug to look into its planned movements when empty. The movements when the tug tows an a/c are not shown because it would be entirely under ATCO responsibility then. The planned trajectories for tugs are computed together with all other vehicles by MAS.

7.1.6 Conflict free routing system

The routing of all aircraft and towing vehicles is done based on a multiagent motion planning algorithm, described in the deliverable D3.1 'Support algorithms for automated tug assignment and path planning'. This two-level routing algorithm uses a low-level search to calculate individual trajectories per aircraft, and coordinates all agents in its high-level search to yield conflict-free trajectories. For the low-level, we extended the existing Safe Interval Path Planning (SIPP) algorithm, and adapted the existing Priority-Based Search (PBS) algorithm to serve as high-level solver. PBS constructs a priority order between agents to deconflict their space-time trajectories. In the low-level search, the route of a deprioritized agent has to be adapted, either by changing its path or altering the speed profile along the path.