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# Towards more automated airport ground operations including engine-off taxiing techniques within the Auto-Steer Taxi at AIRport (ASTAIR) project

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**Abstract:** This paper discusses the SESAR's ASTAIR (Auto-Steer Taxi at Airport) project, which seeks to advance airport ground operations including engine-off taxiing to move a step forward to sustainable airports. The ASTAIR concept integrates Human-AI Teaming to optimize aircraft movement from gates to runways, with the primary objectives of improving predictability, efficiency, and environmental sustainability at large airports. Building on previous initiatives such as SESAR's AEON, ASTAIR brings high-level automation to tasks like autonomous taxiing and vehicle routing. The system assists operators by calculating conflict-free routes for vehicles and dynamically adjusting operations based on real-time data. Based on workshops with several stakeholders, we describe operational challenges for implementing ASTAIR, including managing parking stand availability and adapting to unforeseen events. A significant challenge highlighted is the human-automation partnership, where AI plays a supportive role but humans retain control over critical decisions, particularly in cases of system failure. The need for clear and consistent collaboration between AI and human operators is emphasized to ensure safety, efficiency, and improved compliance with take-off schedules, which in turn facilitates in-flight optimization.

**Keywords:** Airport ground operations; Automation in aviation; Human Automation Teaming; Conflict-free routing; Autonomous taxiing

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## 1. Introduction

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.

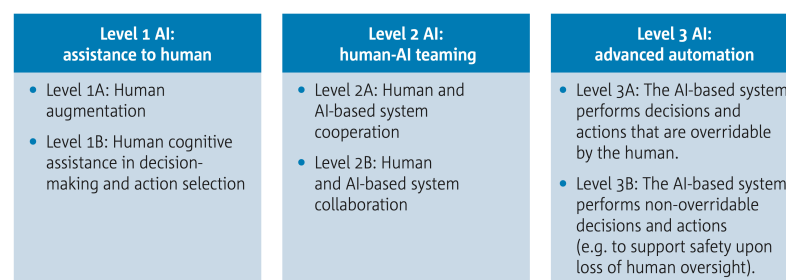
ASTAIR goal is to design a seamless partnership between Human and AI to manage and perform engine-off and conventional taxiing operations on all the airport surfaces (including aircraft and towing vehicles steering from the gates to the runways) at major European airports.

To safely guide all vehicles on the taxiways, it is essential to manage not only the routes they follow but, most importantly, their speeds since it allows deconflicting trajectories. The SESAR AEON project [1] has investigated the management of heterogeneous conventional and engine-off taxi traffic to reduce the taxiing environmental impact. In the resulting concept of operations (CONOPS), tug fleet managers and ground controllers work as a team relying on decision support tools to schedule autonomous resources allocation and optimize vehicle surface movements. Especially, the AI developed in the project AEON[1] and reused in ASTAIR is capable of calculating conflict free routes for all vehicles through speed management.

Increasing the level of automation for both tug fleet managers and ground controllers in ASTAIR could have the potential to increase airport ground traffic capacity while mitigating the impact on human workload and the environment. For example, depending on the level of automation, AI will be able to initiate timely actions such as giving clearances to vehicles on the airport aprons and taxiways according to optimal routes.

Unfortunately, this routing with speed profiles cannot be implemented yet since aircraft taxiing on their jet engines are not finely operated. Nevertheless, solutions are being developed like Taxibot [7], autonomous follow-me cars [8], auto-taxi aircraft [6] and these techniques will allow a better control over trajectories and speeds of mobiles. It becomes reasonable to envision future ground operations as being AI-driven with human supervision for routine tasks, while Human-AI Teaming is employed to manage unexpected events or specific requirements. ASTAIR must consider the challenges of human-automation collaboration, not only in terms of interface design but also technical issues like computing time. These factors can create obstacles in mutual understanding and hinder the ability to share a consistent level of information between humans and machines due to processing delays. Challenges will arise in managing unforeseen situations and specific needs that AI may struggle to anticipate.

ASTAIR aims at defining automation capable of performing complex tasks involved in the management of surface engine-off and conventional taxiing while maintaining human engagement with the automation. Current airport taxi operation procedures have been tailored to optimize human performance while maintaining human workload to a level that does not compromise safety. With the taxi traffic capacity and the human cognitive availability increases offered by high-level automation and optimized execution support, the role of operators and airport operation procedures will significantly change.

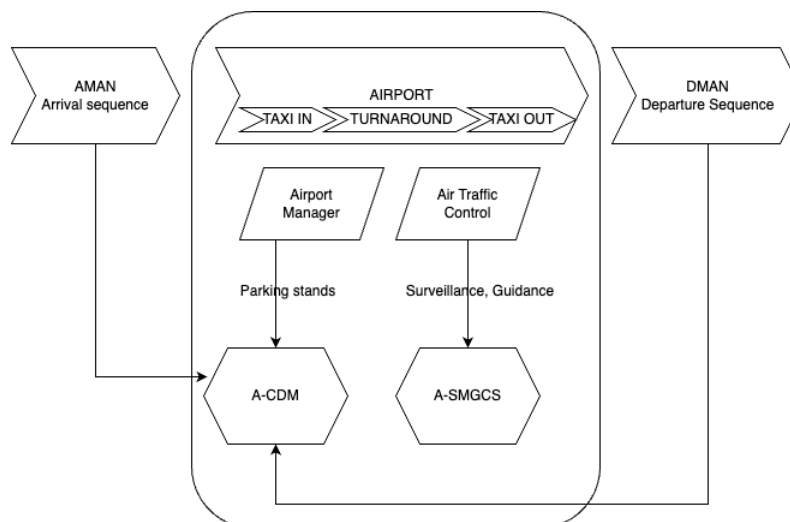


**Figure 1.** EASA Artificial Intelligence Roadmap : Possible classification of AI/ML applications.

ASTAIR objectives are to characterize levels of automation and identify pathways to full automation. For example, AEON's decisional routing support technologies can help shift towards an automated routing clearance system under operator supervision. ASTAIR will explore all automation opportunities and target the 2B level per EASA's AI Roadmap [3] as shown in Figure 1. In this paper, we report our initial efforts to better understand the operational context and identify automation opportunities. We first describe the scope of the project and its envisioned concept of operation. We then describe the results of several workshops and interviews conducted with several stakeholder to identify relevant use cases and associated levels of automation for our CONOPS. We also discuss implications related to human-automation teaming and liability.

## 2. ASTAIR's scope and envisioned concept of operations

ASTAIR concept targets large airports that handle commercial flights, are interconnected to the airports networks and implement a minimum of concepts like airport collaborative decision making (A-CDM) and Advanced Surface Movement Guidance and Control System (A-SMGCS). These constraints are driven by the need to get reliable information on the flight schedules and taxi operations to feed the ASTAIR AI. The counterpart is that it also means large airports with many stakeholders that will need to share their data and constraints. Focused on ground operations, the current airport operations can be summarized as the management and two sequences: arrivals and departures.



**Figure 2.** Current ground operations in a nutshell.

A-CDM [5] is a concept that promotes collaboration among airport stakeholders, including airlines, ATC, ground handlers, and airport operators. 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.

Advanced Surface Movement Guidance and Control Systems (A-SMGCS) [4] play 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 ATCO 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.

### 2.1. Normal operations for a departure aircraft

In the preparation phase of an outbound flight, information are shared amongst the airport operators and in particular the Target Off Block Time (TOBT, the time at which an aircraft is expected to leave its parking position and begin taxiing). When the aircraft is ready to taxi, the captain asks ATCO for a pushback clearance which is delivered once it has been checked that TOBT is respected and the aircraft movement is safe. After pushback, ground ATCO gives routing clearances to the pilot, helped with the A-SMGCS radar image and guides the aircraft to the runway entry. All along the movement, ATCO will check that no other vehicles come in conflict with the aircraft and if needed issue route modification clearance or right-of-way clearances to ensure the safety of movements on the airport platform. After that, line-up and take off are managed by the tower ATCO who the aircraft has been transferred to. Ground ATCO has also the responsibility to bring the aircraft to the runway on time to keep the schedule, the departure sequence, and update flight information if necessary. Indeed, the departure schedule is impacting the overall in-flight traffic and delays may disturbs operations or create less efficient operations.

## 2.2. Normal operations for an arrival aircraft

About 15 minutes in advance, implementation of arrivals manager provides reliable estimated arrival times for inbound traffic. The tower ATCO handles the landing phase and runway movements and then delivers the aircraft to ground ATCO for the taxi phase until the parking position. The stand assigned to the aircraft has been previously assigned in A-CDM platform by the airport operator. Similarly to the outbound taxiing phase, ground ATCO is responsible for the safe and efficient navigation of inbound aircraft to the stands. Ground ATCO will deliver routing clearances to pilots as well. But additional constraints may appear like managing stands availability when departure are delayed and occupy their parking longer than planned.

## 2.3. Envisioned concept of operations

The solution aims to enhance predictability, safety, and efficiency at large airports using A-CDM and A-SMGCS, upgrading guidance services for greater autonomy. It will address vehicles, aircraft, and tow tugs in the movement area, from gate to runway and vice versa. The ASTAIR concept builds on the AEON project results, utilizing ecological routing with speed profiles to compute conflict-free routes for ground vehicles and integrating tow tugs into traffic management.

The ASTAIR AI can forecast 20 minutes of vehicle trajectories, deconflicted by speed regulations, centralizing information from stakeholders to inform routing computations. It provides routing information to ATCO, issues clearances with speed profiles to aircraft and tow tugs, and allocates tow tugs to the Tug Fleet Manager. All data will be updated in real time to adapt to operational events.

For departures, A-CDM allows modification of TOBT up to 5 minutes before the actual time, relayed to tower control. ASTAIR will consider estimated arrival times confirmed 10 to 15 minutes in advance, allowing parking assignments to be modified similarly. It will compute conflict-free routes for the next 20 minutes and adjust as needed, ensuring conflict resolution through speed regulations. Human operators can input constraints or new information to assist AI in managing ground movements.

In summary, ASTAIR seeks to automate A-SMGCS routing and guidance services, enabling airport operators to share information and supervise ground movements. Leveraging AI for conflict-free route computation, routing clearances can be issued automatically, with operators overseeing safe operations and providing updated traffic information.

## 3. Workshops and interviews to explore the concept and identify use cases

### 3.1. Method

In order to explore our envisioned concept of operation and define relevant use cases to further develop and evaluate it, we carried out several activities with stakeholders. We conducted interviews and observations with air traffic controllers, apron managers, ground handlers or airport operators. We also conducted several workshops with stakeholders to identify opportunities for automation; use cases; justifications for the use cases and future needs of an automated airport.

We transcribed the interviews and the workshop results before conducting an analysis to refine our concept and identify relevant use cases.

### 3.2. Results

The workshops highlighted unique airport characteristics and common concerns regarding automation. Each airport's layout significantly impacts operations, revealing that managing parking stands is crucial for smooth ground operations, often more so than runway capacity. For example, CDG's extensive routing network allows for aircraft delays during taxiing, while Frankfurt's limited taxiways necessitate on-the-fly holding spots. All configurations would benefit from computed vehicle routing and speed management to address gate occupancy issues.

A shared feature among the airports is parking along a single taxilane, requiring precise pushback synchronization to avoid aircraft blockages. A 20-minute conflict route computation could assist in this synchronization. Temporary holding points are also used to resolve ground conflicts, with AI potentially aiding in selecting predefined spots and suggesting new locations to enhance operations.

Concerns about automation failures and AI handover were common in interviews. Attention must be paid to AI inputs and tuning for each airport's operations, considering technical constraints like wingspan and vehicle weight, as well as human cognitive limitations. Finding optimal routing may help in recovery scenarios after automation failures.

Managing dead-end taxi lanes and limited remote holding space is critical for Fraport, CDG, and AMS, making holding a key ASTAIR use case. The multi-agent system should also synchronize pushbacks, though this may be a lower priority.

In ground handling, we identified a need for improved mission planning, where AI could optimize resource allocation. Fraport's airport manager oversees the taxi phase, unlike CDG's split responsibilities. ASTAIR would be more efficient managing traffic from gate to runway, potentially optimizing departure sequences for tower control.

Runway configuration changes are frequent at AMS but easier at CDG and Frankfurt. This presents a use case for AMS, where long taxi times complicate rerouting. While full towing is not a universal goal, the trend towards efficient ground operations favors it, with AMS targeting full towing in its roadmap.

Lastly, the implementation of speed management alongside routing introduces various liability concerns. Currently, pilots are responsible for preventing ground collisions. However, if AI systems are given full control over vehicle navigation, the shift in liability will need to be carefully addressed and managed.

### 3.2.1. Selected use cases

The various interviews 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. The selection was driven by the potential of each use case to show the different issues that a higher level of automation would bring in real life ground operations. 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.

#### **Normal Operations**

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. This normal use case aims at showing how to build trust in AI for the operator.

#### **Normal Operations with rescheduling**

The first operational event to be studied will be rescheduling a departure, for instance because of a passenger being late. 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.

#### **Arriving traffic without parking**

In the same manner, the next use case 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. Indeed it is hard for the AI to propose the best one without additional contextual and real

time information from a human operator (expected occupancy time, impacts of parkings reallocation...).

#### **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. ASTAIR validation will focus on the first case to analyse how the service level degradation could be perceived and managed by the human operator. In case of such a failure 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 minutes time frame. If no solution is rapidly found, the system would not totally stop but first revert to a simpler algorithm giving only locally optimal solutions, requiring more attention from the operator. This use case addresses issues with operator's situation awareness on the available service level and information actually processed by AI.

#### **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.

#### **Remote Holding**

Another case in which ASTAIR concept would have an added value is the implementation of departure remote holding process. The remote holding procedure is implemented by certain aircraft operators in response to air traffic control (ATC) notifications of anticipated significant takeoff delays. 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 ATC grants permission for engine restart and taxi to runway. The collaboration between the operators and would lead to optimal timing for restart and potentially to find holding locations that would not disturb other traffics.

#### **Arriving flight with technical issue**

This use case describes a situation in which an arriving aircraft faces an emergency at landing and need 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 for ASTAIR AI.

#### **High level taxi strategy tuning**

This use case describes a situation in which case an operator can adjust the AI routing strategy to respect strictly or not the airport rules (e.g., preferred taxiways directions in specific configurations). 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. Specific recommendations were made toward having the AI using human-like procedures such as known preferred directions or standard holding points to facilitate handover if necessary.

## 4. Discussion 264

### 4.1. Human-Automation Teaming 265

Several expectations and concerns regarding human-automation teaming and the impact of the ASTAIR concept on Human Performances were raised during our workshops. First, we identified that using higher levels of automation on ground operations could shift the roles of humans toward supervisors as illustrated in the proposed use cases. Such a shift poses specific challenges in terms of training but also in maintaining skills and situation awareness. 266-271

Other concerns raised were specifically focused on user confidence with the AI and the system in general. Participants in the workshop expressed concerns about how to handle situations in which the AI could fail. This leads to specific questions such as: *"how to hand over to humans? If manual actions are required, does the operator need to be an ATCO in case of failure?"*. For some, using automation was a way to pack more traffic and as such in case of failure, this would cause high workload on operators taking over. Such results highlight the need to design and assess interactions enabling humans to understand the status of the AI and facilitate handover when necessary. 272-279

### 4.2. Liability 280

A key aspect of the project is assessing its feasibility regarding liability implications among stakeholders. Current liability risks identified in concept development include: 281-282

1. Speed clearances/speed profile: The airport assumes responsibility for incidents if speed clearances are issued. 283-284
  - Solution #1: Advise pilots a point with a time constraint instead of issuing speed clearances, although this may lead to non-conflict-free taxiing. As noted in a workshop, changing recommendations frequently can reduce pilot trust in the system and increase workload. 285-288
  - Solution #2: Have tug drivers manage taxiing while towing aircraft, which would utilize their familiarity with the ASTAIR platform and reduce pilots' mental workloads. 289-291
  - Another suggestion was to use speed recommendations rather than strict constraints, placing the speed management responsibility on pilots. Then the AI that computes conflict free routes shall take into account this additional uncertainty in the execution of its routing clearances. 292-295

Specific safety nets for autonomous taxiing vehicle surveillance and gradual alerting systems may be necessary. 296-297

2. Higher levels of automation: These raise questions about trust in AI and its liability implications. Participants expressed concerns about regulatory views and who is responsible in the event of an incident; for example, a participant noted, "AI can plan, but execution should remain human." 298-301

In summary, the ASTAIR project emphasizes the importance of human responsibility in executing AI-driven plans and the need for effective human-AI Teaming, which will be validated through the project's objectives. Trust in the system and the responsibilities of ATCOs and pilots regarding speed control also require thorough validation and clear communication among stakeholders. 302-306

## 5. Conclusions 307

At this stage of the project, three major constraints to the deployment of the concept have been identified: 308-309

- Vehicles able to follow a routing clearance with speed profile are required. Even though several solutions exist, the resilience of the Multi Agent System towards deviation from plan shall be evaluated as well as the impact on airport capacity. 310-312



- 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. 313-315
- Taking full control on the taxi phase of aircraft gives the full responsibility of the vehicles to airport managers. Potential mitigation solution should be studied. 316-317

Next steps will consist in implementing the concept by designing ASTAIR AI, built on Multi Agent System, together with HMIs that allows supervision of operations and collaboration with the algorithms. Finally, ASTAIR concept shall be validated with a combination of test techniques: 318-321

- Fast Time Simulation to finer validate the multi agent path planning implemented in ASTAIR AI to measure the capacity of the algorithm. 322-323
- Real Time Simulation to showcase the concept and the dedicated HMI designed to facilitate the Human Automation Teaming 324-325
- Workshop with professional operators to validate the feasibility of the concept, although the TRL level is still quite low. 326-327

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