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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 SESAR's Auto-Steer Taxi at Airport (ASTAIR) project, which seeks to advance airport ground operations including engine-off taxiing to move towards 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 the operational challenges involved in 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 upon each flight adhering to its schedule. As a result, improving departure punctuality and smoothing trajectories become essential in realizing the full benefits of in-flight optimization. Today, ground operations are managed by a human operator assisted by decision support tools. In addition, the emergence of engine-off taxiing techniques will increase the number of vehicles to guide due to additional towing tugs. Increasing the level of automation thanks to an artificial intelligence (AI) tool capable of planning conflict-free trajectories, for both departures and arrivals given their interdependent nature, and managing routine movements autonomously, on behalf of the operator, could help to increase the general predictability of airport turnaround operations.

ASTAIR's goal is to create a seamless partnership between humans and AI to manage and perform engine-off and conventional taxiing operations on all airport surfaces (including aircraft and towing vehicles steering from the gate to the runway) at major European airports.

To safely guide all vehicles on the taxiway, it is essential to manage not only the routes that they follow but also, 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 taxiing's 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 resource allocation and optimize vehicle surface movements. In particular, 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 has the potential to increase the airport ground traffic capacity while mitigating the impact on the human workload and the environment. For example, depending on the level of automation, AI will be able to initiate timely actions such as giving clearance 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, such as Taxibot [2], autonomous follow-me cars [3], and auto-taxi aircraft [4], and these techniques will allow better control over the trajectories and speeds of mobile vehicles. It is reasonable to envision future ground operations as being AI-driven with human supervision for routine tasks, while human–AI teaming will be 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 regarding technical issues like the 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. The current airport taxi operation procedures have been tailored to optimize human performance while maintaining the human workload at 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 roles of operators and airport operation procedures will significantly change.

ASTAIR's objectives are to characterize the levels of automation and identify pathways to full automation. For example, AEON's decisional routing support technologies can help to shift towards an automated routing clearance system under operator supervision. ASTAIR will explore all automation opportunities and target the 2B level as per EASA's AI Roadmap [5], 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 stakeholders to identify relevant use cases and associated levels of automation for our CONOPS. We also discuss implications related to human–automation teaming and liability.

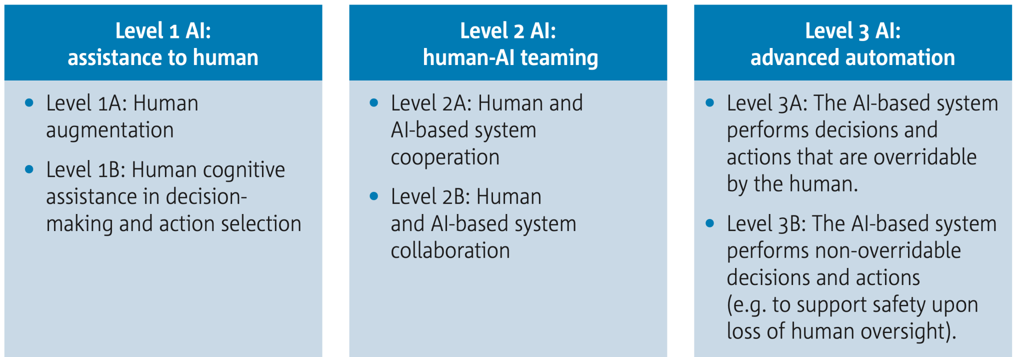

Figure 1. EASA artificial intelligence roadmap: possible classification of AI/ML applications.

2. ASTAIR's Scope and Envisioned Concept of Operations

ASTAIR's concept targets large airports that handle commercial flights. It is interconnected with the airport's networks and implements several basic concepts, like airport collaborative decision making (A-CDM) and advanced surface movement guidance and control systems (A-SMGCS). These constraints are driven by the need to obtain reliable information about the flight schedules and taxi operations to feed the ASTAIR AI as illustrated in Figure 2. The disadvantage is that this also means that large airports with many stakeholders will need to share their data and constraints. Focused on ground operations, the current airport operations can be summarized as the management of two sequences: arrivals and departures.

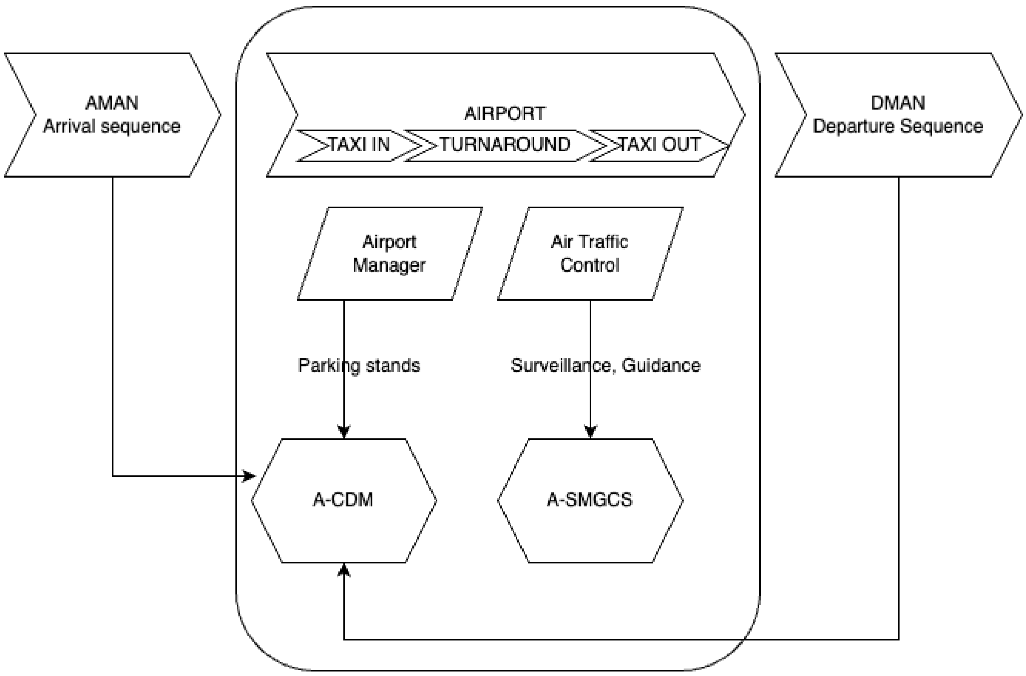

Figure 2. Current ground operations in a nutshell.

A-CDM [6] 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 the 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) [7] play a pivotal role in enhancing the safety and efficiency of aircraft taxi operations. An A-SMGCS is a system specifically designed to enhance the situational awareness of 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.

2.1. Normal Operations for a Departure Aircraft

In the preparation phase of an outbound flight, information is shared among the airport operators, particularly 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 the ATCO for pushback clearance, which is delivered once it has been checked that the TOBT is respected and the aircraft movement is safe. After pushback, the ground ATCO gives routing clearance to the pilot, assisted by the A-SMGCS radar image, and guides the aircraft to the runway entry. Throughout the movement, the ATCO will check that no other vehicles will be in conflict with the aircraft and, if needed, issue route modification clearance or right-of-way clearance to ensure the safety of movements on the airport platform. After this, line-up and take-off are managed by the tower ATCO that the aircraft has been transferred to. The ground ATCO has also the responsibility to bring the aircraft to the runway on time to satisfy the schedule and the departure sequence and to update the flight information if necessary. Indeed, the departure schedule impacts the overall in-flight traffic, and delays may disturb operations or lead to less efficient operations.

2.2. Normal Operations for an Arrival Aircraft

About 15 min in advance, the 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 the ground ATCO for the taxi phase until the parking position is reached. The stand assigned to the aircraft is previously assigned via an A-CDM platform by the airport operator. Similarly to the outbound taxiing phase, the ground ATCO is responsible for the safe and efficient navigation of inbound aircraft to the stands. The ground ATCO will deliver routing clearance to pilots as well. However, additional constraints may appear, such as managing the stand availability when departures are delayed and aircraft occupy their parking positions for longer than planned.

2.3. Envisioned Concept of Operations

The solution aims to enhance the predictability, safety, and efficiency at large airports using A-CDM and A-SMGCS, upgrading the 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's 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 min of vehicle trajectories, deconflicted by speed regulations and centralizing information from stakeholders to inform routing computations. It provides routing information to the 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 the modification of the TOBT up to 5 min before the actual time, being relayed to tower control. ASTAIR will consider estimated arrival times confirmed 10 to 15 min in advance, allowing parking assignments to be modified similarly. It will compute conflict-free routes for the next 20 min and adjust them as needed, ensuring conflict resolution through speed regulations. Human operators can input constraints or new information to assist the 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 the 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 the management of parking stands is crucial for smooth ground operations—often more so than the 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 taxi lane, requiring precise pushback synchronization to avoid aircraft blockages. A 20 min 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 the interviews. Attention must be paid to AI inputs and tuning for each airport's operations, considering technical constraints like the wingspan and vehicle weight, as well as human cognitive limitations. The identification of the 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, although this may be of 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 in managing traffic from gate to runway, potentially optimizing the 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.

Selected Use Cases

The various interviews also enabled us 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 at a low to normal load, the other use cases featured unexpected events that were not included in the planning given to AI algorithms and impact the ground operations through 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 engine start-up, which is not specific to ASTAIR (but to sustainable taxiing, even if not automated). However, artificial intelligence can help to optimize the timings of start-ups. This normal use case aims at showcasing how to build operators' trust in AI.

Normal Operations with Rescheduling

The first operational event to be studied will involve rescheduling a departure—for instance, due to a passenger being late. The aspect under investigation is the impact of the time needed for the AI to integrate this new information and how the system should behave in the meantime, i.e., the operational constraints that it would place on the normal workflow. The visualization of the impacts of rescheduling on other traffic is also considered here.

Arriving Traffic Without Parking

In the same manner, the next use case examines an unexpected event for an arrival aircraft and the unavailability of its parking position, with the previous aircraft being late for departure. In this case, an interesting aspect to investigate would be the different potential solutions. Indeed, it is challenging for AI to propose the best one without additional contextual and real-time information from a human operator (expected occupancy time, impacts of parking reallocation, etc.).

Automation Failure

Dealing with a higher level of automation, a use case focusing on automation failure is inevitable. Malfunctions could occur at two levels in the ASTAIR concept: either the AI fails to compute a conflict-free solution with the given planning or the vehicles that automatically follow the routing and speed clearances issued by the AI deviate from the computed solution. ASTAIR's validation will focus on the first case to analyze how service-level degradation could be perceived and managed by the human operator. In the case of such a failure to find a conflict-free solution with new traffic or constraints, the system would still be able to perform safe operations for a limited time, as the previously found solution covers a 20 min time frame. If no solution is rapidly found, the system would not stop completely but would first revert to a simpler algorithm, giving only locally optimal solutions, requiring more attention from the operator. This use case addresses issues with the operator's situational awareness regarding the available service level and the information actually processed by the AI.

Runway Mode of Operation Modification

In the case of runway mode of operation (RMO) modification, many aircraft and vehicles need to be re-routed in a short period of time. The point of interest here for the

ASTAIR concept is the different timings of operations compared to the current operations. Indeed, today, once a decision regarding an RMO change is implemented, the new route's computation can occur rapidly for a human operator, but the implementation of these routings can be time-consuming due to the number of pilots to contact and the number of clearances to issue. In contrast, ASTAIR's AI may only require a few minutes to compute the new routing and speed clearances, and the implementation of the solution would be rapid thanks to its automated digital communications.

Remote Holding

Another case in which the ASTAIR concept would have added value is in the implementation of the 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 take-off 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 at designated remote parking stands. At this location, the engines are turned off and the ATC grants permission for the aircraft to restart and taxi to the runway. The collaboration between the operators would lead to optimal timing for restart and potentially enable them to find holding locations that would not disturb other traffic.

Arriving Flights with Technical Issues

This use case describes a situation in which an arriving aircraft faces an emergency at landing and needs to quickly reach its parking stand or requires inspection while escorting the aircraft to the parking stand. In this case, the human operator may wish to rapidly create a route for the aircraft and set it as a new constraint for the ASTAIR AI regarding the routing of other aircraft and vehicles. This manually set route would reduce the potential solutions for the ASTAIR AI.

High-Level Taxi Strategy Tuning

This use case describes a situation in which an operator can adjust the AI routing strategy to strictly adhere or not adhere to the airport's rules (e.g., preferred taxiway directions in specific configurations). For instance, when the operator expects a lower traffic load in the next hour, the level of compliance with the rules can be relaxed to give more freedom to the ASTAIR AI. The solutions found may be more efficient, even if the complexity of the situation increases and it would potentially be more difficult for the operator to take over the operations. In contrast, such a feature could be useful to prepare for human handover. Specific recommendations were made in terms of having the AI use human-like procedures, such as adhering to known preferred directions or standard holding points to facilitate handover if necessary.

4. Discussion

4.1. Human–Automation Teaming

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

Other concerns raised were specifically focused on user confidence with the AI and the system in general. The participants in the workshop expressed concerns about how to handle situations in which the AI could fail. This led to specific questions such as how to hand over to humans and, if manual actions are required, whether the operator needs to be an ATCO in case of failure. For some, using automation was seen a strategy to increase traffic, and, as such, in the case of failure, this would create a large workload for the operators who take over. Such results highlight the need to design and assess such interactions, enabling humans to understand the status of the AI and facilitate handover when necessary.

4.2. Liability

A key aspect of the project is assessing its feasibility regarding liability implications among stakeholders. The current liability risks identified in concept development include the following.

1. Speed clearances/speed profiles: The airport assumes responsibility for incidents if speed clearances are issued.
    - Solution #1: Advise pilots regarding 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 the recommendations frequently can reduce pilots' trust in the system and increase their workload.
    - Solution #2: Have tug drivers manage taxiing while towing the aircraft, which would utilize their familiarity with the ASTAIR platform and reduce pilots' mental workload.
    - Use speed recommendations rather than strict constraints, placing the speed management responsibility on pilots. Then, the AI that computes conflict-free routes will take into account this additional uncertainty in the execution of its routing clearances.

    Specific safety nets for autonomous taxiing vehicle surveillance and gradual alerting systems may be necessary.
2. Higher levels of automation: These raise questions about trust in AI and its liability implications. The participants expressed concerns about regulatory views and responsibility in the event of an incident; for example, a participant noted, "AI can plan, but execution should remain human".

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.

5. Conclusions

At this stage of the project, three major constraints to the deployment of the concept have been identified.

- Vehicles able to follow routing clearance with speed profiles are required. Although several solutions exist, the resilience of the multi-agent system under deviations from the plan should be evaluated, as well as the impact on the airport capacity.
- 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.
- Taking full control on the taxi phase of aircraft gives the full responsibility of the vehicle to airport managers. Potential mitigation solutions should be studied.

The next steps will consist of implementing the concept by designing the ASTAIR AI, built on a multi-agent system, together with HMIs that allow the supervision of operations and collaboration with the algorithms. Finally, the ASTAIR concept will be validated with a combination of test techniques:

- Fast-time simulation to finely validate the multi-agent path planning implemented in the ASTAIR AI to measure the capacity of the algorithm;
- Real-time simulation to showcase the concept and the dedicated HMI designed to facilitate human–automation teaming;
- Workshops with professional operators to validate the feasibility of the concept, although the TRL level is still quite low.

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References

1. Advanced Engine Off Navigation, Project Website. Available online: https://www.aeon-project.eu/ (accessed on 1 September 2024).
2. Taxibot Home Site. Available online: https://taxibot-international.com/ (accessed on 1 September 2024).
3. Usher AI Home Site. Available online: https://usher-ai.com/ (accessed on 1 September 2024).
4. Autonomous Airbus Aces Autopilot Taxi, Takeoff and Landing Tests, New Atlas. Available online: https://newatlas.com/aircraft/airbus-attol-autonomous-airliner/ (accessed on 7 May 2024).
5. Human Centric Approach to AI in Aviation, May 2023 Version 2.0. Available online: https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-roadmap-20 (accessed on 1 September 2024).
6. Airport Collaborative Decision-Making (A-CDM) Implementation Manual, March 2017 Version 5.0. Available online: https://www.eurocontrol.int/concept/airport-collaborative-decision-making (accessed on 1 September 2024).
7. EUROCONTROL Specification for A-SMGCS Services, 22 April 2020 Edition 2.0. Available online: https://www.eurocontrol.int/publication/eurocontrol-specification-smgcs-services (accessed on 1 September 2024).