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AEON

ADVANCED ENGINE OFF NAVIGATION

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Abstract

This document is the final version of the SPR-INTEROP/OSED for the AEON Solution "Advanced Engine-off Navigation" for V1 phase after any validation exercises have been performed on this subject. It provides the final set of safety, performance, and interoperability requirements of the AEON solution in the specific context of the operational service and environment definition defined as relevant.

According to the standard SESAR SPR-INTEROPOSED template, this version of the SPR-INTEROP/OSED includes 3 sections, presenting respectively the introduction and background of the document, the Operational Service and Environment Definition of the proposed solution and is the core part of the document and an initial set of safety, performance, and interoperability requirements as well as a first discussion about cost-benefits.

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1 Executive Summary

The SESAR Exploratory Research Project AEON (Advanced Engine-off Navigation) proposes a solution for enhancing airport ground operations and reducing their environmental impact, based on the coordinated and collaborative usage of three classes of greener taxiing solutions, namely single-engine taxiing solutions, non-autonomous solutions (i.e., involving external systems such as tugs) and autonomous taxiing solutions (i.e., based on electric motors on board the aircraft).

The CONOPS developed by the AEON project is intended to be able to contribute to the purposes of the ATM Masterplan [46]. In particular, the solution proposed can be considered suitably related to the roadmap defined towards two main objectives of the strategy: the ground automation based on solutions for runway status and surface management and the roadmap for innovative environment friendly solutions, to enable airports, ANSPs and airspace users to optimise trajectories, including on the ground.

This deliverable takes as input the research reported in deliverable D1.3 'State of the Art' [1], which identifies the state-of-the-art methodologies for collaborative Human-Machine Interactions, multi-agent systems and operational research for the management of a fleet of electric/hybrid towing vehicles. The document also identifies a first set of projects and research initiatives on related subjects that were considered as a reference and to avoid overlaps.

Since this is one of the key documents of the project, it feeds most of the activities carried out in the project. It is important to consider that this document is expected to be read in parallel with the deliverables being released following the validation activities, which include a discussion on how this concept could impact on a number of key performance indicators (KPA), such as human performance, safety, capacity, environmental impact and proactive liability allocation in case of an accident.

This version of the SPR-INTEROP/OSED includes 3 sections, presenting respectively the introduction and background of the document, the Operational Service and Environment Definition of the proposed solution and is the core part of the document and an initial set of safety, performance, and interoperability requirements and a first discussion about cost-benefits.

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2 Introduction

Aircraft jet engines are very efficient when it comes to flying, but their efficiency decreases when taxiing. Considering that taxiing time account from 10 to 30 % of flight time in Europe [2], and that 36% of the fuel is burned on a standard Landing and Take-off cycle [3] many solutions started being developed to mitigate the emissions produced at ground level [4]. These solutions can be divided into two groups:

- autonomous techniques such as electric engines embedded in the rear or landing gear, and
- non-autonomous technique in which tugs vehicles coupled to the aircraft and controlled by the pilot allows taxiing operations.

An additional technique is often used to reduce fuel consumption in surface movements, the single engine taxiing operations. Nonetheless, this require the use of jet engines therefore its benefit is limited compared to the one of the other techniques. But this solution is not the only one associated with drawback. As a matter of facts each taxiing technique has advantages and downsides. Autonomous electric taxiing aircraft have lower dynamic performances (speed and acceleration), non-autonomous solutions add new vehicles to be managed on the taxiways (empty tugs). Moreover, these techniques share the need for engines warmup and start management for departing aircraft. For this reason, Single Engine Taxiing (SET) is used mainly for taxi-in of arriving aircraft and almost never for departures [5].

This deliverable aims to present how the AEON concept aims to integrate these promising techniques to overcome the specific limitations each one has and achieve the overarching goal of making ground operations more sustainable and eco-friendlier.

2.1 Purpose of the document

The SESAR Solution Development Life Cycle aims to structure and perform the work at project level and progressively increase SESAR Solution maturity, with the final goal of delivering a SESAR Solution data pack for industrialisation and deployment. The SPR-INTEROP/OSED represents one of the key parts of the SESAR Solution data pack. When complete, it is structured in several parts. Part I provides the Safety and Performance Requirements (SPR) and Interoperability Requirements (INTEROP) related to the solution presented, in the context of the Operational Service and Environment Definition (OSED), which describes the environment, assumptions, etc. that are applicable to the SPR and INTEROP requirements. Parts II to V provide the series of assessments performed at SESAR Solution level that justify the SPR and INTEROP requirements. For this reason, it is planned to be periodically revised and enriched as soon as the SESAR Solution progresses in the development life cycle.

In this framework, the present document provides the final version of the SPR-INTEROP/OSED of the AEON SESAR Solution. It is developed for V1 phase, as AEON is classified as applied exploratory project, and includes only Part I to present the changes that will result from the deployment of the AEON concept of operations.

2.2 Scope

This document is the SPR-INTEROP/OSED for the AEON Solution "Advanced Engine-off Navigation" for V1 phase. **It provides the final set of safety, performance, and interoperability requirements of the AEON solution in the specific context of the operational service and environment definition defined as relevant.**

The aims of the AEON Project are to perform research supporting future implementation of green taxiing techniques and to provide a set of tools and interfaces for the different ground operators, supported by dedicated algorithms to improve the allocation of towing vehicles and path planning efficiency. It targets mainly the ground handlers, the airport management, and the ATC operators. The objective is to support these actors in sharing their constraints to decide together on the best usage of the different available taxiing techniques for each flight and then manage potential operational events that would prevent the initial plan to deliver correctly.

2.3 Related Documents

This deliverable results from the integration of the results produced by the different project work packages. It takes as input the preliminary description of operations provided in D1.1 "Concept of Operations Initial Version" [6] which describes the Operational Service and Environment Definition of the proposed solution and an initial set of safety, performance and interoperability requirements as well as a first discussion about cost-benefits. The document also take profit from the results produced in the validation activities as part of WP5 such as D5.1 "Solution Assessment Plan" [7], D5.2 "HP Assessment Report" [8], D5.3 "Safety Assessment Report" [9] and D5.4 "Cost Assessment" [10].

In addition, the description of operations provided in the present document is influenced by the results of several other deliverables such as D2.1 "Models and algorithms for autonomous and non-autonomous taxiing operations" [11] and D2.2 "Model for optimal allocation of towing vehicles" [12] to flights both at the strategic long/medium planning and tactical execution phase of the operations, regarding the design of the algorithm involved in the management of the fleet of tugs and the path planning. The WP3 deliverables D3.1 "Representative use case definition" [13] and D3.2 "Supervision HMIs" [14] that describe the use cases and HMIs that were used in the validation activities and helped refining the preliminary concept of operations. And finally, D4.2 "Description of the final validation platform" [15] from the WP4 describes the platform employed in the final validation activities.

For the sake of clarity and conciseness, this document will present the final version of the CONOPS, focusing on its main operative aspects. Compared to the description reported in D1.1, readers here will find a sharper and more immediate analysis. Extended inquiries and references are available in the dedicated deliverables linked in the References.

2.4 Intended readership

The intended audience of this SPR-INTEROP/OSED document includes:

- The key stakeholders targeted by the solution, in particular ground handlers, airport management, airlines, ATC operators and the industry providing green taxiing solutions, most of which are also represented in the AEON Advisory Board
- The AEON Consortium

- The SJU
- The overall aviation community interested in the document, as it will be publicly available

2.5 Structure of the document

In addition to the present introduction, this version of the SPR-INTEROP/OSED includes 2 sections.

- Section 3 presents the Operational Service and Environment Definition of the proposed solution and is the core part of the document.
- Section 4 presents a final set of safety, performance, and interoperability requirements and a first discussion about cost-benefits.

Although the provision of SPR-INTEROP requirements is not required from the exploratory research project, the Consortium decided to add them to provide a more complete view of the operational concept.

2.6 List of Acronyms

Acronym	Definition
AC	Apron Controller
ACC	Air Traffic Control Centre
A-CDM	Airport Collaborative Decision Making
AEON	Advanced Engine Off Navigation
AIBT	Actual In-Block Time
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOBT	Actual Off-Block Time
AOP	Airport Operating Plan
APOC	Airport Operations Centre
APTO	Airport Operator
APU	Aircraft Power Unit
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
CNS	Communication Navigation and Surveillance
CO_2	Carbon dioxide

CONOPS	Concept of Operations
CPDLC	Controller Pilot Data-Link Communication
CR	Change Request
CTOT	Calculated Take Off Time
D-ATIS	Datalink Automatic Terminal Information Service
DET	Dual Engine Taxi
DPI	Departure Planning Information
D-TAXI	Datalink Services used for Provision of Ground-related Clearances and Information
Dx.x.	Deliverable x.x
EASA	European Air Space Agency
E-ATMS	European Air Traffic Management System
EOBT	Estimated Off-Block Time
ERA	Equipment Restraint Area
ETA	Expected Time of Arrival
EU	European Union
EXIT	Taxi-In
EXOT	Taxi-Out
FAA	Federal Aviation Administration
FC	Flight Crew
FMU	Flow Management Unit
FO	First Officer
FOD	Foreign Object Damage
GC	Ground Controller
GH	Ground Handler
GS	Ground Staff
GT	Ground Time
HMI	Human Machine Interface
HO	Headset Operator
HPAR	Human Performance Assessment Report
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization

INTEROP	Interoperability Requirements
KPA	Key Performance Area
KPI	Key Performance Indicator
LAQ	Local Air Quality
LTO	Landing and Take Off (cycle)
LVC	Low-Visibility Condition
NB	Narrow Body
NM	Network Manager
NMOC	Network Management Operational Centre
NOP	Network Operating Plan
NOTAM	Notice To AirMen
NOx	Nitrogen Oxides
OI	Operational Improvement
OP	Outbound Planner
OPAR	Operational Performance Assessment Report
OSED	Operational Service and Environment Definition
PAR	Performance Assessment Report
PDS	Pre-Departure Sequencing
PDSP	Pre-Departure Sequencing Procedure
PIC	Pilot In Command
PIRM	Programme Information Reference Model
QoS	Quality of Service
R&D	Research & Development
RTF	Radiotelephony
RTT	Road Trip Time
RWY	Runway
SAC	Safety Criteria
SAR	Safety Assessment Report
SecAR	Security Assessment Report
SESAR	Single European Sky ATM Research Programme
SET	Single Engine Taxi
SJU	SESAR Joint Undertaking

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SPR	Safety and Performance Requirements
SWIM	System Wide Information Model
TD	Tug Driver
TFM	Tug Fleet Manager
TOBT	Target Off-Block Time
TS	Technical Specification
TSAT	Target Start-Up Approval Time
TT	Towbar
TWY	Taxiway
VDGS	Visual Docking Guidance System
VTT	Variable Taxi Time
WB	Wide Body
WP	Work Package
WW	Wing Walker

Table 1: List of acronyms

3 Operational Service and Environment Definition

The AEON solution proposes a novel operational concept for sustainable and efficient operations on the grounds. Thanks to the combination of different classes of engine-off techniques, the purpose is to reduce the environmental impact of taxiing operations without affecting capacity, safety, and human performance. The techniques considered involve single-engine taxiing solutions, hybrid towing taxiing solutions and autonomous taxiing solutions based on electric engines.

The operational concept is based on the belief that these taxiing techniques may become robust solutions and technologies in the future and there will be the need for them to coexist in the airport environment and to be used in a coordinated way. By means of a set of dedicated tools and interfaces for the different ground operators, as well as dedicated algorithms, the AEON solution aims at supporting such stakeholders in sharing their constraints to decide together on the best usage of the different available taxiing techniques for each flight, and then manage potential operational events that would prevent the initial plan to deliver correctly.

Considering the above, the AEON solution is planned to influence ground operations at different time phases of the planning, and to involve a variety of different operators both in the long/medium-term planning and execution phases of the procedures.

The AEON solution is planned to influence ground operations at different time phases of the planning and to involve a variety of different operators, as represented in the following concept image.

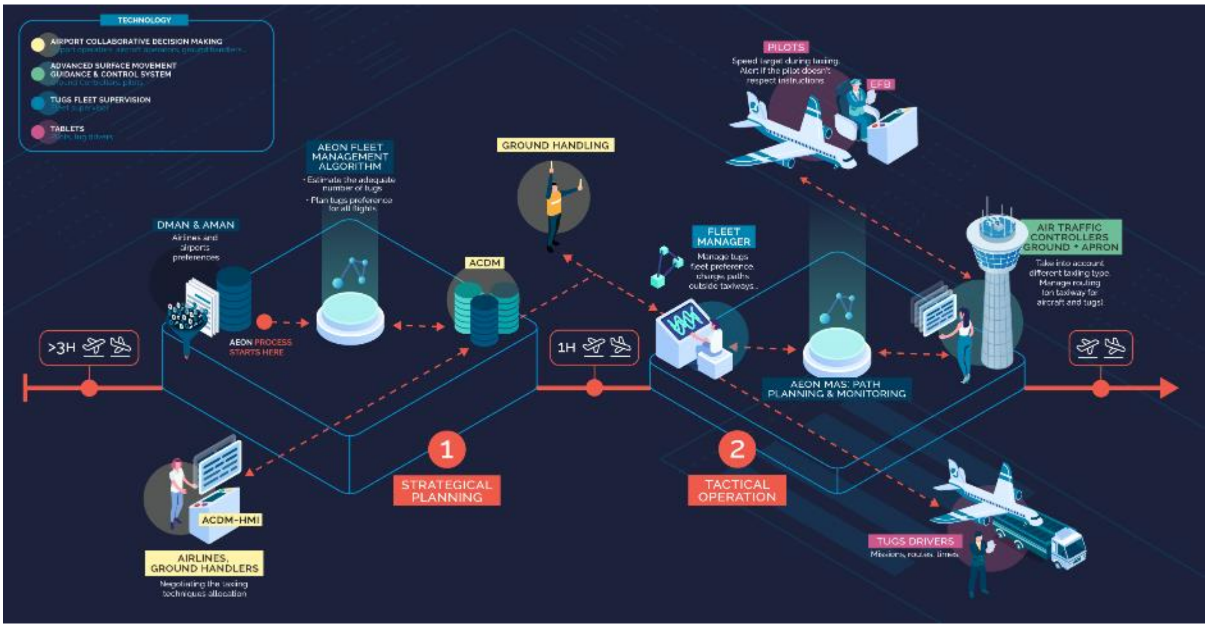

Figure 1: AEON Concept Image

At **strategical long/medium planning phase**, a support tool will help estimate the adequate number of tug vehicles to operate a given airport considering its specific traffic. Then the best allocations of taxiing technique to each arriving and departing aircraft will be provided considering the arrival and departure sequences plus the operational constraints of the tugs fleet. Then the allocations will be proposed to the different actors through the Airport Collaborative Decision Making (A-CDM) portal. They will have until one hour before the Target Start-Up Approval Time (TSAT) to freeze the decision to accommodate with last minute operational events.

Afterwards, for the **tactical execution phase**, AEON provides HMIs for ATC officers and pilots to manage the actual taxiing. Advanced Surface Movement Guidance and Control System (A-SMGCS) HMIs will:

- identify the taxiing techniques of each aircraft,
- help define the taxi clearances, especially for towed departing aircraft that will need to stop for detaching process somewhere without disturbing the rest of traffic,
- give real-time updates on remaining taxi time to give to the pilot to facilitate engines start-up procedure, and
- help reassign tug vehicles when operational events modify the initial plan.

In addition, the AEON solution considers that the aircraft using electrical engines for taxiing (or towed by tugs) are more easily controlled on speed, *i.e.*, they can take speed target and follow them. Since the common drawback to all engine off taxiing techniques is the lower acceleration level, it would be highly beneficial to avoid stop and go. AEON could thus provide speed target to avoid aircraft arriving simultaneously on the same intersection, hence smoothing traffic control. Furthermore, AEON will explore the possibility to give speed cues to the pilot through datalink, to be displayed on the electronic flight bag to avoid additional workload and radio frequency usage for ATC.

The AEON concept of operations assumes tug vehicles to use taxiways both when coupled with an aircraft or when empty. The validation activities show interesting results concerning the use of service roads to relieve congested taxiways and reduce ATCOs workload [8]. Service roads usage shall be further investigated in future research to quantify the impact on the overall operational concept.

Green taxiing techniques into practice: a preliminary roadmap

Over the research progress, the techniques considered registered remarkable evolutions. Analogous developments interested also the related technological supports, but with different levels of maturity. For this reason, the preliminary assumptions of the AEON solutions have been integrated with more reliable evidence and data.

The technologies identified for improving ground operations are typically already available and their wider adoption depends on the balance between their costs and perceived benefits [16]. Notoriously, SET represents the most common green taxiing technique now currently in use. In this regard, there may be considerable improvements, mainly related to the more frequent usage of this methods when the aircraft and the contextual conditions allow it. Among the three techniques considered in AEON, special attention instead should be addressed to the more innovative ones, namely e-taxing and towing.

As anticipated in several deliverables of the AEON project, electric-powered alternatives are still under investigation. Despite that, the literature review indicates that both autonomous (e-taxi) and non-autonomous (tug vehicles) techniques may be useful in the airport environment [16].

E-taxi specifically includes systems for larger (twin-aisle or wide-body) aircraft with electric motors in the aircraft's wheels to drive it, with the required electric power being generated by the on-board APU, a small gas turbine engine that runs using the same fuel as the main aircraft engines. E-taxiing technology enables aircraft to be taxied across the tarmac using electric engines and could reduce fleet emissions by 3 to 5% if applied widely [17].

On the contrary, considering non-autonomous techniques, the use of electric options presents a more diversified and fragmented scenarios. Over the last decade, the use of towing solutions has been corroborated, but opting for fuel, diesel of hybrid versions. However, among these different alternatives, only hybrid ones could be considered for greener taxi advancements. These latter allow to tow the aircraft from the gate to close to the runway and vice-versa, but at the moment present the limitation to be suitable only for single-aisle (narrow-body) aircraft.

The solutions here at issue not only demonstrate promising perspectives individually considered. What is more relevant concerns the development and deployment they may achieve if integrated within a unique airport context. Indeed, the combined and coordinated use of all these alternatives would mitigate the intrinsic shortcomings of each of them since now, taking advantage of the ecological benefits. This clearly demonstrates how technological readiness is not the only factor at play. Indeed, the different perks and drawbacks assessed in the survey carried out at the beginning of the AEON project [23] testify how a combined approach is necessary to foster the implementation of autonomous and non-autonomous taxiing techniques [16].

Operational improvements and enablers

The AEON solutions will have an impact on three main aspects, namely:

- Collaboration on predeparture sequencing in A-CDM
- Routing and supervision in A-SMGCS plus interaction enhancements
- Communications of clearances and traffic information to pilots and vehicles drivers via Datalink.

Assumptions

As anticipated above, the AEON solution is based on a set of assumptions and considerations, which are summarised hereafter.

1. The operational concept moves from the consideration that in the future the different engine-off taxiing techniques considered by the project will become deployed and robust technologies, and will coexist in the same airport environment, even if at present they have different levels of maturity.

2. The operational concept assumes that the AEON solution will be able to take into account the specific strengths and potential challenges and drawbacks of each of the engine off techniques considered and will use this information to set their integration in the airport environment.

3. The AEON solution considers that the aircraft using e-taxi systems for taxiing (or towed by tugs) are more easily controlled on speed, *i.e.*, they can take speed target and follow them.

4. The AEON routing system assume that the empty tug vehicles will use the taxiway system as the service road network is not sufficient.

5. Concerning the airport capacity, every tool designed in AEON solution aim at respecting the planned flight schedules, thus trying not impacting the capacity.

3.1 Detailed Operational Environment

The operational environment described in the initial OSED associated the AEON concept with all kinds of ground operations in the airport environments, from high to low complexity. Applying such a concept to low complexity airport environments implies a significant simplification and it should lead to potential new solutions. In particular, autonomous taxiing solutions may fit smaller airports better than non-autonomous solutions. In such airports, the taxi time is short enough not to be impacted by the lower speed of the e-taxi systems, while the benefit of non-autonomous solutions would be limited. However, as described in the Solution Assessment Plan [7], more emphasis was put on airports characterised by complex ground operations.

In such complex environment, it is noticed that during the landing and take-off (LTO) cycle, on average the aircraft spend most of the time on the ground, as they have to 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.

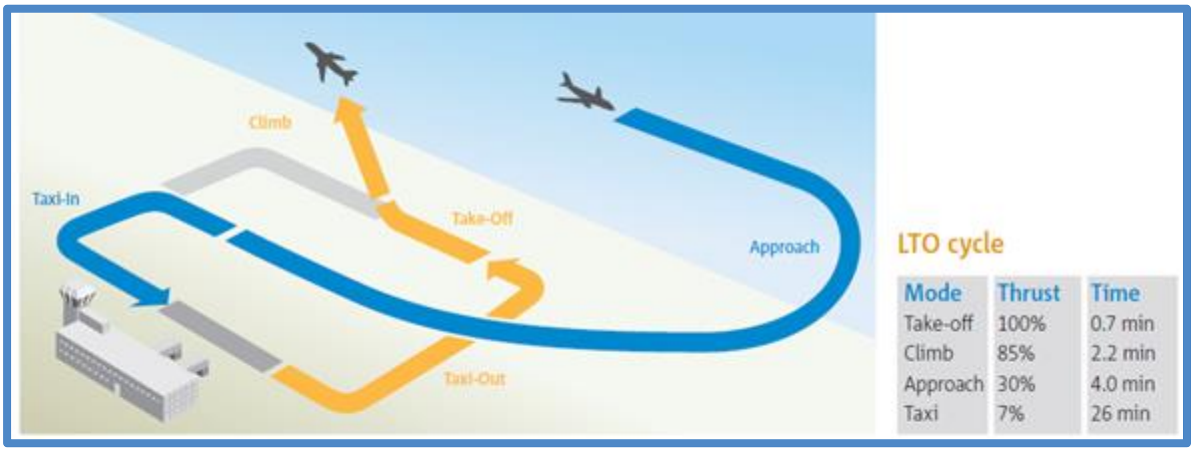

Figure 2: Landing and take-off cycle

3.1.1 Operational Characteristics

The operational characteristics of the solutions proposed will enable airport operators to operate the aircraft on the ground using different engine-off techniques. The different requirements and proposed solutions look at having airport operate a mix of traditional, autonomous, and non-autonomous taxiing aircraft. Although the mix itself do not require specific modifications, the impacts are listed and sorted by techniques in chapter 3.1.3.

These techniques can be operated using external means or onboard aircraft systems. They can also be used independently or in combination by adopting an engine-off solution with an engine-on method.

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For example, a single-engine taxi could be supplemented with the e-taxi technique (here referred to as '*Hybrid*' mode) to achieve a specific operational objective. The services are either provided by the Airport Operator (APTO) or by the Aircraft Operator / Ground Handler (AO/GH).

In addition, the methodology of operating can be pre-selected using HMI enabled tools that are integrated into existing A-CDM platforms. The operational characteristics offer aviation stakeholders both flexibility and optimization of the fleet in addition to other benefits. The concept of operations (CONOPS) provided can be used for both independent and *hybrid* mode of operation, as per the situational awareness. However, the current operations do not offer complete engine-off techniques that are integrated into an HMI interface platform.

3.1.2 Roles and Responsibilities

In principle, the AEON solution primarily affects the roles and responsibilities of most of the actors involved in day-to-day ground operations of the airport. The following list provides the roles involved, while more details about how they are expected to be impacted are proposed in Section 3.2.3. Please notice that at this stage of the concept development the Network Management (NM) is not considered impacted. The NM may not be interested in what happens in the taxiing operations, *i.e.*, how the information is generated or what elements are considered for its elaboration should be transparent for the NM.

Here below there are listed the roles mainly influenced by the AEON solution, and the impacts of this innovation of their respective tasks and responsibilities.

1. **Airport Operator (APTO)** is intended as a natural or legal person engaged in or offering to engage in an airport operation. In AEON, these subjects are required to take part in the strategic long/medium-term planning phase accepting or suggesting the most profitable taxiing techniques.

2. **Airlines / Aircraft Operators (AOs)** are intended as natural or legal persons engaged in or offering to engage in air services. In AEON, these subjects 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.

3. **Air Navigation Service Providers (ANSPs)** and **Air Traffic Service Providers (ATSPs)** generally include the services provided by Air Traffic Controllers (ATCOs) working at airports for the arrival and the departure flight phases, and in Air Traffic Control Centres (ACCs) for the en-route flight phase. In AEON, 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 Tug Fleet Manager (TFM) and supervise the taxiing operations according to the suggestions provided by the AEON system.

4. **Tug Fleet Manager (TFM)** is a new 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. The AEON concept considers it as a single person, but the role can be performed also by a group of individuals.

5. **Pushback Operator** 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 (§ 3.2.2.2), while the introduction of non-autonomous techniques will require personnel qualified to operate such solutions (i.e., attaching or detaching the tug to the aircraft).

6. **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, s/he 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 AC and GC. Furtherly, s/he interacts with the TFM whose provide instructions for new missions (§ 3.2.2.3).
7. **Flight Crew (FC)** is intended as the personnel responsible for the operation of an aircraft during the flight. The two main actors are the Pilot in Command (PIC) and First Officer (FO). With AEON, they are supplied with information about taxiing operations, specifying the taxiing technique adopted for the flight and the associated taxiways operations. In AEON, the PIC of an aircraft equipped with an autonomous taxiing technique is expected to perform taxiing operation including pushback (§ 3.2.2.2). With non-autonomous techniques, PIC's control in taxiing operations remain constant as the TD will hand control over to the PIC once performed pushback with the non-autonomous solution (e.g., a tug vehicle). Once the PIC regains control over the aircraft, s/he performs taxiing steering via tiller and nose gear and braking via the aircraft brakes (§ 3.2.2.3).

3.1.3 Impacts on already existing systems and tools

AEON project has identified several operational restrictions to the deployment of engine off techniques. Even though the AEON solutions implementation would require an integration with existing systems to be fully efficient, some benefits could however come with low impact or modification. Thus, parts of the solution could be deployed on non CDM airports or non-A-SMGCS airports. A summary of the prerequisites for each technique for a faster deployment are listed in the table below:

	Prerequisite	Potential solution
Common to all techniques	Taxi technique in use for each aircraft for better situation awareness	• Aircraft equipment database update + Shared information • A-CDM modification • ASMGCS radar image improvement • Any shared data source between stakeholders
	Safe engines start up zones identification	• Airport aeronautical maps update • ASMGCS radar image improvement

	Remaining taxi time / Engine start up time	• ATCO estimates • A-SMGCS modifications with taxi time computation
	Handle lower dynamic performance / smoother taxiing for lower consumption	A-SMGCS modifications with speed profiles computation
	Procedures clarifications	Airlines / airframes documentation updates
Single Engine Taxiing	Nothing specific	Nothing specific
Non-Autonomous technique	Tugs loading and unloading zones identification	Airport aeronautical maps update
	Handle additional vehicles on the ground	Tug Fleet Manager role
Autonomous technique	Nothing specific	Nothing specific

Table 2: AEON prerequisites

Even if most of the prerequisites can be mitigated at first with temporary solution, for a more effective implementation, the AEON solution is expected to mainly impact two solutions already existing and used in the airport environment, namely:

- Total Airport Management, particularly the Airport Collaborative Decision-Making application (A-CDM), since the taxiing techniques are impacting the taxi time, and the airport resources availability and
- the A-SMGCS due to the guidance service with speed cues for pilots and drivers.

A detailed description of the consequences the AEON solution will have on these solutions is provided in the following sections.

3.1.3.1 Total Airport Management

Total Airport Management solution[1] PJ.04-01 'Enhanced Collaborative Airport Performance Planning and Monitoring' builds on the framework of A-CDM and propose to add landside processes in the airport dashboard. Hence the ecological taxiing will have an impact on the processes. AEON targets airports of group 1 and 2 as defined.

[1] https://cordis.europa.eu/project/id/733121/results

According to the EUROCONTROL A-CDM Implementation manual Version 5.0 (31 March 2017), the different actors involved in the use of the system have to provide specific sets of information, according to their tasks and responsibilities (a list of the high-level information about the impact of AEON of these tasks is available at § 3.2.3).

For the purpose of the AEON solution, it's particularly interesting to notice that:

- Aircraft Operator/Ground Handler is responsible for Target Off-Block Time (TOBT) updates that will be affected by taxi technique allocation
- Airport gives stand and gate allocation; this will be completed with tug vehicle availability when requested.
- Air Traffic Controllers inform the pilots about the taxi time before pushback, the variable taxi times computation will be modified according to the taxi technique in use.
- Pilots know their EOBT/TSAT from the display at their gate/parking stand and that's their responsibility to call the ATC to get clearance to leave the parking/apron before TSAT

The Consortium analysed the impact of the AEON solution on the current functioning of the ACDMs according to the milestone approach for turnaround process. The integrations operated by the AEON solution does not add any additional milestone. Instead, it will use Target Start-up Approval Time (TSAT) issue as the time to freeze the taxi technique allocation for further computation and routing. Indeed, if the taxi technique is decided for a given a/c in this phase, then it leaves enough time for the ground handlers to organize accordingly. In the same manner, taxiing techniques for inbound aircraft shall be determined before Estimated Time of Arrival. However, any unforeseen operational event may prevent this technique to be used in the end and the taxi strategy will need to be adapted to cope with it, but then it is no longer part of the A-CDM process [6].

In addition, Variable Taxi Times computations will be enhanced by the AEON solution. With a better knowledge of the taxiing techniques used, the algorithms will be able to provide more precise taxi times and re-evaluate them regularly to take into account the actual operational situation. Moreover, these taxi times will also be provided to the ATC officer to keep the pilot updated with the latest information.

Finally, the Pre-departure A-CDM feature will be the main modification of the process since it will include a new step of taxiing techniques allocations. A negotiation may be needed between the different actors if the requested technique is not applicable, or the schedule is too tight.

3.1.3.2 Advanced Surface Movement Guidance and Control System

For AEON, the Consortium uses as reference the EUROCONTROL Specification for Advanced Surface Movement Guidance and Control System A-SMGCS (EUROCONTROL-SPEC-171 ed. 2.0, 22 April 2020). In particular, the attention converged on the four services the system provides: Surveillance Service, Airport Safety Support Service, Routing Service, Guidance Service.

In this regard, the surveillance service is not impacted functionally by the AEON solution. The only potential difference with respect to current operations concerns aircraft towed by tugs, but in that case, it shall behave exactly as towed aircraft. Empty tugs driving alone will have their own transponder and appear on the radar image in the same manner as a service vehicle does. However, the taxiing technique planned (prospectively, it should include even the method in use) for a given aircraft shall appear in its labelling or representation. All the actors involved should mutually check the consistency of the techniques adopted, both over the planning and the execution phases. In the same manner, the Airport Safety Support Service shall still operate as usual.

The AEON solution will follow the routing service specification as currently stated. However, to reduce the Controller workload, it will explore the possibility to use technologies under development within SESAR such as Datalink for routing clearances.

Finally, only the Guidance service specification is impacted by the AEON solution with the proposition of a new function to give speed cues to aircraft pilots and vehicles drivers.

3.1.4 Applicable standards and regulations

The AEON solution offers a concept and a system for using engine-off techniques keeping in mind the existing and future aviation standards and regulations. The solution involves industrial products and services that are at different levels of maturity and certification.

The overall concept of operation is designed to follow all the relevant ICAO (International Civil Aviation Organisation) and EASA (European Union Aviation Safety Agency) regulations. Although there are no standard and regulation that are followed in the SESAR solution, few notable ones are used to define the framework of the CONOPS, namely ICAO 4444 [24], ICAO Annex 14 [25] and IATA IGOM (9th Edition) [26].

Standards and regulations below are provided to serve as reference in this document. They are not required as pre-requisites to the Lite APOC concept, no applicable standards, and regulations.

3.1.4.1 A-CDM

There is currently no implementing rule for A-CDM (yet) but there is a European Standard (ETSI EN 303 212) "Airport Collaborative Decision Making (A-CDM); Community Specification for application under the Single European Sky Interoperability Regulation EC 552/2004"[39].

In addition, several EUROCAE documents (European Standards) of relevance are:

1. ED-141 System Requirements Document [40]
2. ED-145 Interface Definition Document [41]
3. ED-146 Test and Validation Document [42]

These are considered to ensure interoperability between technical system enablers, when adhered to.

3.1.4.2 A-SMGCS

The implementation of A-SMGCS [43] and its various services is a local decision based on the needs of an aerodrome and any national or regional mandates. There is EUROCONTROL Specification, which describes the Services (Surveillance, Airport Safety Support, Routing and Guidance) and requirements of the Advanced-Surface Movement Guidance and Control System (A-SMGCS) to support their implementation at an aerodrome.

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3.2 Detailed operating method

AEON must deal with a series of factual and technical limitations. As anticipated, some of the taxi techniques considered by the CONOPS are at their early stage of development, still far to be consolidated and ready-to-use solutions. This section, therefore, will present the current and the envisioned operating methods considered by the project.

Since today's ground operating methods involve keeping the main engines-on or using single-engine techniques to taxi aircraft from gate to runway or vice versa [6], the attention will first converge on the current operating methods used in different ground phases (3.2.1). In this case, Dual Engine Taxi (DET) is normally adopted during both Taxi-Out (EXOT) and Taxi-In (EXIT) phases of aircraft ground operations. The Single Engine Taxi (SET) method is usually used by airlines during the EXIT phase more than the EXOT phase, to save fuel during longer taxiing times at the airports [27]. Moreover, in the EXOT phase the pilot will eventually have to start both engines to prepare for tack-off. It may be easy to them to start them right away rather than later while they need to check many other things before take-off. After landing, pilots usually don't need both engines to taxi to the gates.

Afterwards, the analysis will cover the new operative methods envisioned by AEON, prospectively approaching the autonomous and non-autonomous taxiing techniques and the impacts of their integrated use in current and future operations.

3.2.1 Current operating methods used in different ground phases

This section provides information about how the various phases of the flight on the ground are currently managed. In this regard, SET is the new norm of operations that should be followed, specially to reduce fuel consumption. In SET operations, both the departure and arrival procedures follow a sequence of activities like dual-engine taxiing, except for using a single engine-on. The PIC decides when to switch on or off the second engine(s) for warm-up/cooling down processes, before take-off or after landing. In the following sections, DET and SET are to be intended interchangeably since their deployment does not impact the operating methods when the PIC decides accordingly to the working context (*i.e.,* avoiding using SET when prohibited by airlines policies). Indeed, at present, airports still have not regulated or formulated a specific procedure for single engine taxiing, but airlines and manufacturing companies have started developing their own procedures [27][28].

3.2.1.1 Pushback

The pushback is the movement of an aircraft from a nose-in parking stand using the power of a specialized ground vehicle attached to or supporting the nose landing gear. It is commonly the second part of a taxi in push out procedure at airport terminal gates and will be necessary to depart from all except self-manoeuvring parking stands unless the aircraft type is capable of power back and local procedures allow this.

Once the Pilot in Command (PIC), has given the confirmation of 'brakes released' to the person in charge of the ground crew who are to carry out the "Pushback", the ground crew becomes temporarily responsible for the safe manoeuvring of the aircraft in accordance with either promulgated standard procedures or as specifically agreed beforehand. SET operations don't have an impact on pushback.

The step-by-step concept of operation of a typical narrow body aircraft that uses both the engines-on while departing and arriving has been illustrated in Section 3.2.1.1 of D1.1 [6].

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3.2.1.2 Taxi-Out

Taxi-out (EXOT) is the term used during the departure of an aircraft, which includes the pushback procedure and is defined by the time taken for the aircraft to move from Point Gate or Parking stand to Runway take-off point as show below in Figure 3.

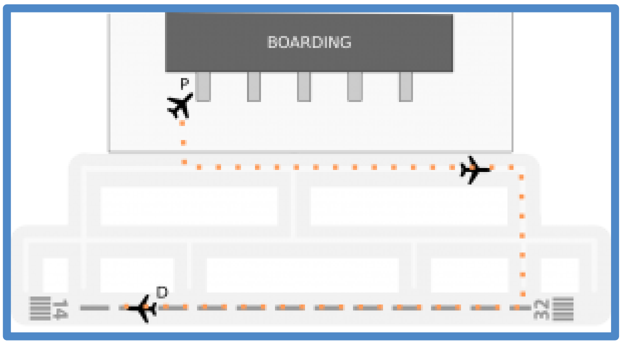

Figure 3: EXOT time calculation methodology

After being cleared by the ground crew and with the warmed-up engines, the PIC is able and has to taxi according to the instructions/clearances received from the ground controller (or ATC) to designated hold points (near the proposed take-off runway or de-icing pads or along with the taxiways etc.). During this taxi phase, the PIC has full responsibility of the aircraft and operates it based on the local safety and environmental conditions, handing over the control during pushback. **The choice of speed to drive through taxiways would depend largely on pilot situation awareness, airport speed limitations and airline internal policies.** It is often seen at many airports that where speed limitations are not set the pilots operate the aircraft at a highest speed in order to achieve the allotted Calculated Take-Off Time (CTOT). Normally, based on the respective airport operating plan, the routings of the departing aircraft are planned in a way to avoid intersection conflicts, jet blasts or any other safety concerns and aid in quicker and seamless exits. The PIC should have the situational awareness of the airport they are operating both under normal and non-normal/LVC conditions.

The Flight Crew and the ATCO/Ground Controller are in constant touch to exchange any real time updates and guidance. Today, most ANSP at airports update real time data through D-ATIS (Datalink Automatic Terminal Information Service) that enhances the safety for the Flight Crew and reduces interaction time with the ATCOs.

A typical taxi-out procedure along with the communication between Pilot-Ground Controller/ ATC are described in Section 3.3.1.2. of D1.1 [6] and will not be presented here for the sake of briefness.

3.2.1.3 Taxi-In

Taxi-in (EXIT) is the term used during the arrival of an aircraft. It is defined by the time taken by the aircraft to move from the runway touch down to Parking stand or Gate as shown in Figure 4.

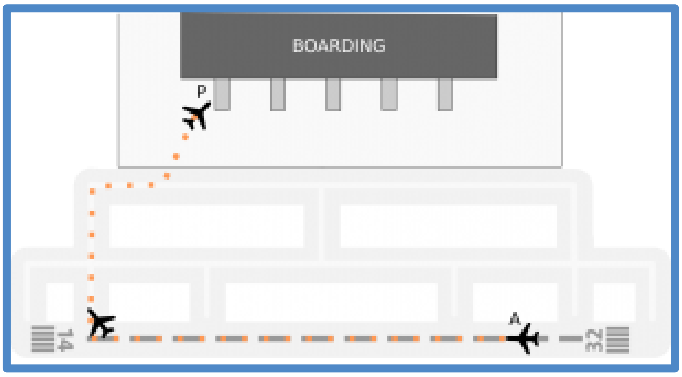

Figure 4: EXIT time calculation methodology

The arrival part of the sequence is rather seamless and has limited or less stops on the ground, till the aircraft reaches the designated stand. Once the PIC touches down the aircraft on the runway and exits to a taxiway, the Flight Crew is instructed by the ATCO to contact the Ground Crew to be guided to the parking stand. It is important to mention that, **upon entering the taxiway the PIC either operate all engines or taxi using single engine**.

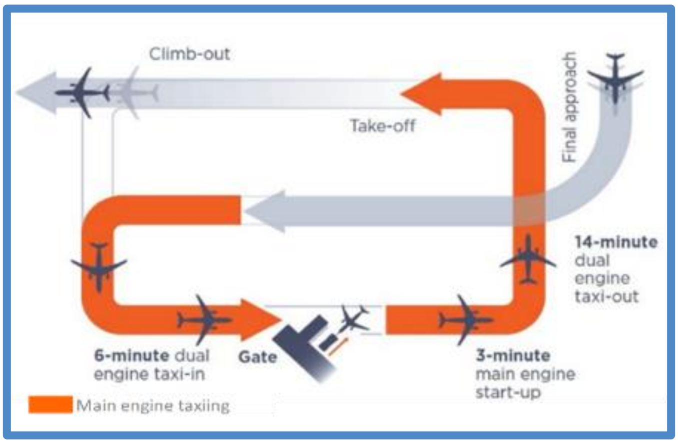

Figure 5: Main Engine-on footprint during LTO

In order to best achieve an optimised round-trip time (RTT) or turnaround, the Airline Operator/Flight Crew and the Ground Staff consider three main variables, namely: the EXIT and EXOT parameters (also commonly called as VTT - variable taxi times) and the Ground time (GT) indicating the time spent by the aircraft between Actual In-Block Time (AIBT) and Actual Off-Block Time (AOBT).

3.2.1.4 Use of pre-departure sequencing tool

The pre-departure sequencing (PDS) tool constitutes a fundamental component of the Airport Collaborative Decision Making (A-CDM) process [6]. In this regard, to achieve the best optimised airside-terminal operations, the real time sharing of information about various processes and aircraft positions are vital. Therefore, the PDS tool acts as a dashboard to collate both arrival and departure flight status. It also helps the aviation stakeholders to make real time data-based decisions at the time of crisis or disruptions.

The Airline Operator/Ground Handler can file the flight plan Estimated Off-Block Time (EOBT)- 3hours, while the CTOT is issued EOBT-2 hours and the TSAT is provided based on the airside / network capacity constraint anytime between TSAT – 40 min to TSAT – 10 min. The existing PDS procedure does not provide options to choose the different taxiing techniques (DET or SET).

The DPIs (Departure Planning Information) are constantly updated and sent to NM/ANSP at respective stages of aircraft readiness (on departure) while the Flow Management Unit (FMU) messages are sent through the network manager or NMOC to the CDM airport that provides real time update of the aircraft landing time at the destination point. The turnaround time along with the EXIT and EXOT times are key performance indicators for the efficient ground operations that are monitored using the A-CDM tool.

3.2.2 New AEON Operating Method

As anticipated in Chapter 3, the AEON project moves from the consideration that aircraft engines are highly efficient at the en-route phase, while on the ground they use much more energy than the one actually needed to move on land [2].

The AEON concept aims to integrate non-autonomous, autonomous and single-engine taxiing techniques to overcome the specific limitations each one has and make ground operations more sustainable and eco-friendlier. Despite the diffusion of single engine taxiing operations in the EXIT phase [27], the description of the new operating method proposed by the AEON Consortium focus on the three categories. This is done following the assumption that, even if at the present the techniques may have different maturity level, soon their maturity will be aligned, and their deployment will be achievable through their integration.

3.2.2.1 Single-Engine Taxi (SET)

Single engine taxiing (SET) procedures are nowadays more frequently adopted by the airlines upon arrivals rather than departures. One of the many reasons beyond this choice, apart from fuel savings, include lower known risks associated to operating single engine compared to the same operation on departure using delayed start-up and warm-up activities. This is especially true after a successful flight (either short, medium, or long haul) using all up engines and having landed safely. Moreover, SET may increase the airside safety risk profile of an airport from a point of view of jet blast [6].

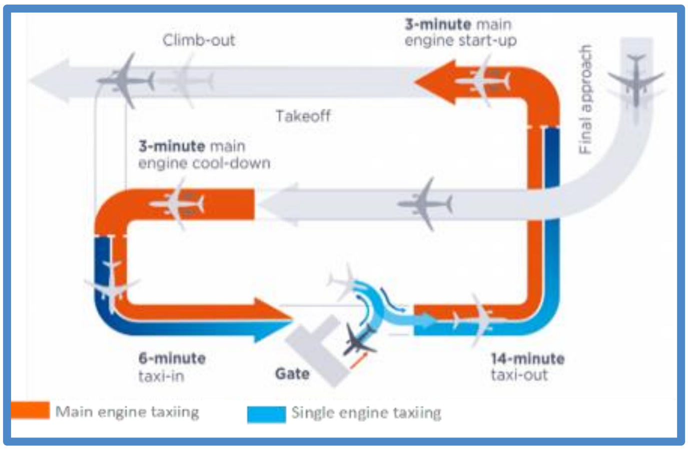

Figure 6: Single Engine-off footprint during LTO

In SET, both the departure and arrival procedures follow a similar sequence of activities that the current operations do at the airports, except for the fact it is operated using single engine-on. The PIC gets to decide when to switch on or off the second engine(s) for warm up/cooling down processes, prior to take-off or after landing. The decision to switch on or off the engines also depend on the respective airline policies. These are generally drafted keeping in mind the safety aspects of aircraft, ground crew and, also, from a maintenance standpoint [6].

3.2.2.2 Autonomous taxiing operations

An autonomous taxiing solution is an on-board electric taxi system embedded in the nose or main landing gear[2]. It enables pilot-controlled forward and reverse movement in gate and terminal areas without tractors or jet engines. The technology also comes with optional camera/sensor systems that will provide pilots with improved situational awareness for all manoeuvres. The e-taxi is designed to reserve the use of the aircraft engines for take-off and flight. It practically eliminates engine usage during ground movement except during engine start-up, warm-up, and taxi onto the runway. The e-taxi systems offer vast advantages in turnaround and ground times for both airlines and airports. The Equipment Restraint Area (ERA) may need to be re-defined to account for e-taxi aircraft. The lack of engine intake or engine blast risks might positively influence risk and improve risk mitigation.

Figure 7: An e-taxi system or electric green taxiing system (EGTS)

The main difference seen on ground operation is the shift of responsibility for pushback (or *wheelback*[3]) from the Ground Staff to the PIC, during normal operations. Once the GS confirms the ground is ready for *wheelback*, the PIC confirms the use of e-taxi to the Ground Staff. Upon confirmation from the apron controller, the Flight Crew *wheelbacks* the aircraft to the designated point to begin the taxi operation.

The pilot control the e-taxi 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. As per the airside operational constraints, the PIC can decide to start the engines during the taxiing phase of the aircraft or after reaching the designated cut-off point.

On arrival, the aircraft can automatically shift into the e-taxi mode or follow the Hybrid mode, where the e-taxi system is engaged, and one engine is engaged in idle to support breakaway in stop-and-go situations. **Even though e-taxi systems speed can range between 9 to 20 Knots/ hour on the ground, some autonomous taxiing solutions (particularly those installed in the nose landing gear) may adopt a hybrid mode of operation to gain speed during taxiing as their speed is reduced [6].** The PIC/AO have the complete flexibility to operate the aircraft either on e-taxi or *hybrid mode* based on need, regulation, and slot requirements. In the event of a *hybrid mode* of operation, wherein

[2] In this document, the terms "autonomous taxiing solutions" and "e-taxi systems" are used interchangeably

[3] The term "*wheelback*" was introduced in D1.1 [6] to refer to an aircraft using its onboard e-taxi system to move in reverse, as opposed to "pushback," referring to either a legacy tug with a towbar or towbar-less tractor.

the PIC decides to start-up the single engine, the aircraft can be taxied to the taxiway holding point close to the runway, based on the speed limitations.

During the *hybrid mode* of operation, the e-taxi system also shifts either electric mode when the speed of the aircraft moves below 9 knots or cuts-off to an engine mode when the speed extends beyond 9knots/hour. A typical "wheelback/engine-off and late start-up departure procedure" for e-taxi mode of operation, along with actions taken by various accountable stakeholders is listed in Table 3.

Step	Action outbound	Action from
1	Route clearance	Delivery (ATC)
2	Ready call within TSAT window	Pilot
3	Determine TTOT	Outbound Planner (ATC)
5	Ground ready call	Ground Staff (GS)
6	Clearance for *wheelback*	Apron Controller (AC)
7	Wheel back clearance to the GS	Pilot
8	Perform *wheelback*	Pilot
9	Taxi instructions to pilot	Ground Controller (GC)
10	Taxi out to hold point location using e-taxi and/or using *hybrid mode*	Pilot
11	Taxi out to runway	Pilot
12	At runway transfer aircraft to Air Traffic Controller	Ground Controller (GC)

Table 3: Action taken and accountable stakeholder for e-taxiing operations.

Figure 8, Figure 9 and Figure 10 illustrate the LTO cycle using e-taxi systems installed on the nose landing gear, *hybrid mode* (SET/e-taxi) and e-taxi systems installed on the main landing gear.

It is assumed that the taxi distance from apron to the designated point (EXOT phase) are fixed and the distance from the designated arrival point to the apron (EXIT phase) are also fixed and remain constant in all the methods. The situational awareness is also assumed to be common for all the autonomous taxiing solutions, as illustrated in their respective LTO cycles.

As evident from Figure 8, the time taken during the EXOT phase using the nose landing gear e-taxi systems operation would be about 30 min, which includes the engine-off time of about 26-27 min. This is calculated based on the maximum speed achievable. On the EXIT phase, 13 min of taxi-in time including the 3-4 min of engine cooling is calculated with an engine-off time of about 9-10 min.

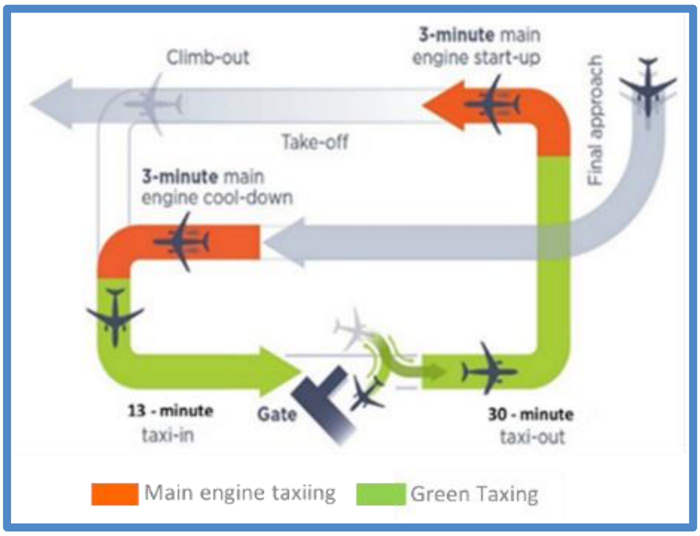

Figure 8: LTO cycle for e-taxi systems installed on the nose landing gear.

Figure 9 shows the *hybrid mode* of operating nose landing gear e-taxi systems, wherein 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. We can notice that the taxi times have reduced compared to the nose landing gear e-taxi systems option in both EXIT and EXOT phases due to required speed achieved using the hybrid mode of operation.

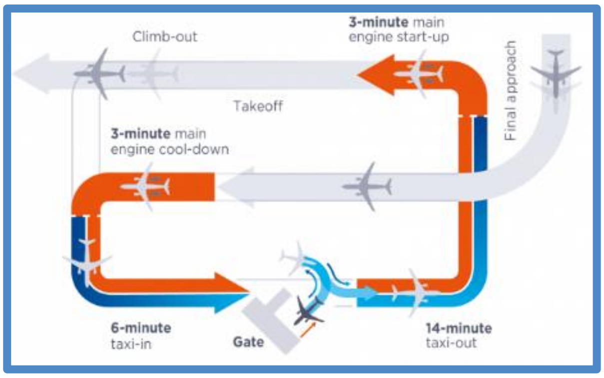

Figure 9: LTO cycle for hybrid operation (SET/e-taxi).

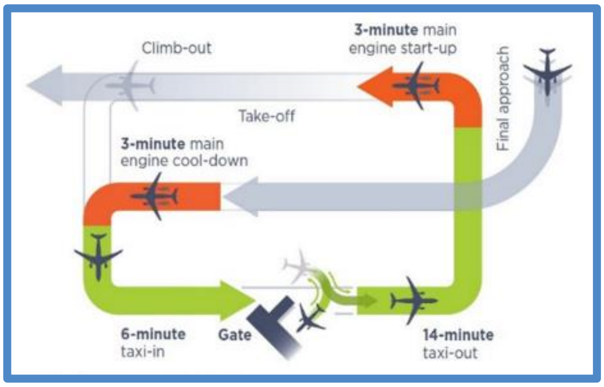

Figure 10: LTO cycle for e-taxi systems installed on the main landing gear.

Figure 10 shows the taxiing operation using main landing gear e-taxi systems, wherein all engines are off during both the EXOT and EXIT phases up to the engine start-up or cooling down point. We can notice here that, not only the taxi times have reduced compared to the nose landing gear e-taxi systems option, but other parameters such as fuel, noise, CO2 emission have gained maximum reductions.

Taxi operations utilizing single engines and e-taxi systems will change operating methods, but only slightly compared to towing vehicles. The changes introduced by the increased number of vehicles and, therefore, those of ground movements that will follow the deployment of non-autonomous taxiing operations are described in the following section.

3.2.2.3 Non-Autonomous taxiing operations

3.2.2.3.1 Operation

A non-autonomous taxiing solution is intended to be a towing vehicle that allows aircraft to taxi for departure to the runway end without the use of the engines. It may also be used for arrival aircraft with some procedure change after the aircraft has left the rapid exit track. It was specially 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.

During the EXOT 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 PIC 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 auxiliary power unit (APU) supply power to the aircraft electrical and hydraulic systems. The system provides the same turning radius of a normal aircraft, with the added benefit of giving better traction in slippery conditions. All these factors make tug vehicles good for both EXOT and EXIT phases. Furthermore, most aircraft require no modifications to use towing vehicles, even though the validation activities shown that aircraft may need to be certified [8].

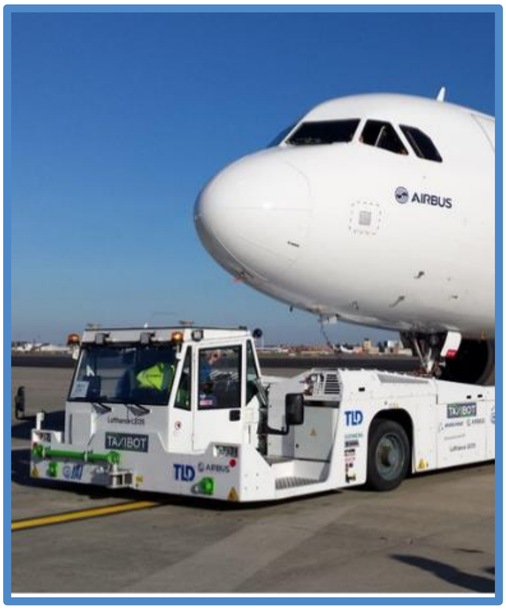

Figure 11. Towing vehicle coupled to an aircraft.

In the EXOT phase, the tug vehicles need to be coupled at the "*coupling point*" (*i.e.,* de-icing area) on the apron and cleared for pushback by the Ground Controller to the Ground Staff and Flight Crew. Once coupled, the Tug Driver will handle pushback operations until the gate/stand in the same manner as it is done today. As soon as pushback is completed, the control is handed over the PIC to taxi until the uncoupling area. The aircraft engines can be started even if the aircraft is still connected to towing vehicle based on the situational awareness, closer to the assigned runway end. Once uncoupled, the control returns to the Tug Driver, whose receive instructions from the Tug Fleet Manager on its next mission.

In the EXIT phase, the aircraft will find a tug stationed at an area as close as possible to the runway designated by the AOP. Once the aircraft reaches the designated coupling point, the Tug Driver attach the tug to the aircraft nose wheel and hand the control over the pilot for taxiing operations. As soon as the coupling process ends, the PIC can taxi the aircraft to the gate/parking stand with engines turning off. Upon reaching the parking stand, the PIC gives the control back to the Tug Driver to uncouple and prepare itself for the next assignment.

A typical "*pushback/engine off and late start-up departure procedure*" for non-autonomous taxiing solutions along with actions taken by various accountable actors is listed in Table 4.

Step	Action outbound	Action from
1	Route clearance	Delivery (ATC)
2	Ready call within TSAT window	Pilot

3	Determine TTOT	Outbound Planner (ATC)
4	Coupling tug vehicle	Tug Driver
5	Ground ready call	Tug Driver
6	Clearance for push-back	Ground Controller (GC)
7	Pushback clearance to driver	Pilot
8	Perform pushback	Tug Driver
9	Switch to pilot (control) mode	Tug Driver
10	Confirm pilot mode	Pilot
11	Ready to taxi signal	Tug Driver
12	Taxi instructions to pilot	Ground Controller (GC)
13	Taxi out to uncouple area	Pilot
14	Uncouple tug vehicle	Tug Driver
15	Start-up engines (potentially while taxiing)	Pilot
16	All clear signal	Tug Driver
17	Taxi clearance	Ground Controller (GC)
18	Taxi out to runway	Pilot
19	At runway transfer aircraft to Air Traffic Controller	Ground Controller (GC)

Table 4: Action taken and accountable actors for departure procedure.

A typical "*Arrival/engine off procedure*" for non-autonomous taxiing solutions along with actions taken by various accountable actors is listed in Table 5 .

Step	Action Inbound	Action from
1	Designate landing runway	Air Traffic Controller (ATC)
2	Landing on designated runway	Pilot
3	At runway exit transfer aircraft to Ground Controller	Air Traffic Controller (ATC)
4	Exit Runway (RWY) and hold in Taxiway (TWY) at designated coupling points	Ground Controller (GC)
5	Engines – Off	Pilot
6	Coupling tug vehicle	Tug Driver
7	Switch to pilot (control) mode	Tug Driver
8	Ready to taxi signal	Tug Driver
9	Taxi instructions to pilot	Ground Controller (GC)
10	At Apron transfer aircraft to Apron control	Ground Controller (GC)
11	Proceed for parking the aircraft	Apron Controller (AC)
12	Aircraft parked at designated apron stand	Pilot
13	Uncouple tug vehicle	Pilot
14	Switch to Driver (control) mode	Tug Driver
15	Drive back to the next assignment	Tug Driver

Table 5: Action taken and accountable actors for arrival procedure.

The non-autonomous taxiing operation are expected to provide significant positive benefits to the overall operation at airports by:

- reducing emissions and noise at airports
- saving fuel and engine maintenance during taxi phase for airlines.

- Improved ground operations safety through enhanced control and monitoring of aircraft ground movements.

Erreur ! Source du renvoi introuvable. illustrates the LTO cycle using a non-autonomous technique. Out of 14min of taxi-out time, the engine-off phase can be about 10-11 min, while about 3-4 min are used for engine-start procedures. However, engine cool-down/start-up is also possible while moving on tug power.

On average, 20 minutes of taxi time can be saved in the LTO cycle using non-autonomous techniques, while the towing vehicle pulls the aircraft (controlled by the FC) to the parking stand/gate during taxiing-in phase.

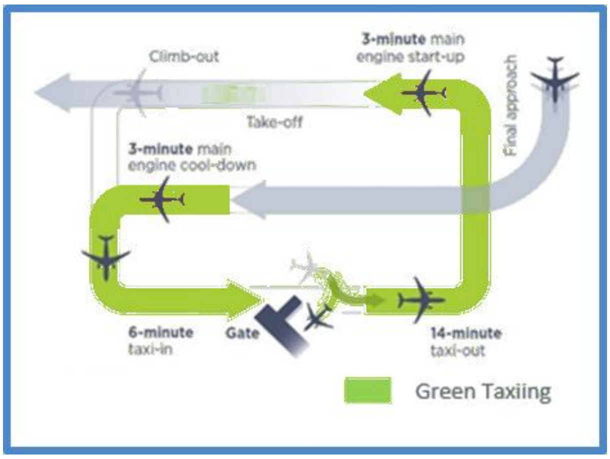

Figure 12: non-autonomous solutions footprint during LTO cycle.

3.2.2.3.2 Fleet Management

Depending on the economic model applied, the deployment of tug vehicles could be proposed either by the airport (APTO), the airline (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 [8].

In the CONOPs procedure, it is assumed 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.

The Tug Fleet Manager (TFM) is a new role introduced by the AEON solution, whose purpose is 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.

In particular, the TFM shall know in advance the predefined coupling and uncoupling points close to the runways to direct the Tug Drivers towards those areas. Secondly, the TFM shall consider the tug schedule resulting from the AEON fleet allocation tool (Section 3.2.2.4.2) as well as the optimal routes from the path planning tool (Section 3.2.2.4.3). Based on these outputs, the TFM shall contact Tug Drivers to give them missions and designed path.

In order to assign a mission to an empty tug vehicle, the TFM contacts the TD to allocate an arriving or departing aircraft designed by the fleet allocation tool. In the communication, the TFM states the TD to which is referring to, then s/he informs the TD about the coupling point to reach, the path to follow, the aircraft to couple with and the uncoupling location (*e.g.,* “Tug Vehicle 12 reach coupling point A, or Stand 12, via TS11 to tow AF1934 to runway 2L”).

The mission information will arrive via datalink on the tablet inside the tug. Then, the TD coordinates with the Ground ATCO to reach the coupling point in a safety compliant manner. Once reached the coupling point the TD can follow two types of procedures, depending on whether the aircraft to couple is departing (Table 4) or arriving (Table 5). In place of aircraft leaving the parking zone to reach the gate, the procedure will be like those described in Table 4.

The Ground ATCO will have to provide clearances to the Tug Driver each time s/he has to operate on the taxiways. As resulted by the human performance assessment [8], the increased exchange of communications may introduce additional workload for Ground ATCOs. The additional workload could be mitigated through an improved network of service roads, probably dedicated to tugs to ensure schedule will not be broken by another service vehicle with low priority. Service roads might allow TDs to reach designated points without requiring clearances from the Ground ATCO or requiring clearances only when services roads intersect taxiways.

3.2.2.4 New AEON solutions integration

The AEON concept of operation aims to provide and operationalize dedicated supporting tools for enabling the introduction of engine-off taxiing techniques. In particular, the project 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 subparagraphs that follow illustrate the integrations apported to the A-CDM and the algorithms and HMIs developed for a proper implementation of the AEON solution into practice[4].

3.2.2.4.1 AEON integration with the A-CDM

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 ACDM 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, while the CTOT is issued EOBT-2 hours and the TSAT is provided based on the airside/network capacity constraint 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. These options give an advantage to both the airport and the airlines in understanding total carbon emission/estimated fuel saved during a particular aircraft operation. Further, the A-CDM platform can also be redesigned/customised to provide an environmental dashboard that would provide a total view of the engine-off techniques used by the AO in the last one hour or so, the fuel saved, and the emission reduction achieved (if we have relevant metrics to be

[4] The description of algorithms, software and HMIs is taken and adapted from the paper: Cousy, M., Peyruqueou, V., Pierre, C., Priou, C., Vo, D. B., Garcia, J., Mitici, M., van Oosterom, S., Sharpanskykh, A., von der Burg, M., Roling, P., Spiller, E., Gottofredi, S., & Lanzi, P. (2022). AEON: TOWARD A CONCEPT OF OPERATION AND TOOLS FOR SUPPORTING ENGINE-OFF NAVIGATION FOR GROUND OPERATIONS. Towards Sustainable Aviation Summit, 18-20 October 2022, Toulouse [29].

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displayed). These can be further customised for a day, month, and year to date etc. The rest of the A-CDM tool remains unchanged and is not impacted. Integration of the AEON CONOPS into the A-CDM enriches the entire platform and gathers data and provides insights into various taxiing techniques used by the AO/GH.

Alle these choices take place during the long/medium planning phase (*i.e.*, up to 1 hour before the flight is scheduled) and have an impact on the taxi speed and hence on the flight's in-block or off-block time. These also influence the organisation of ground handling activities. Given these choices and tug availability, a first set of support algorithm computes an initial tug allocation plan.

3.2.2.4.2 AEON fleet allocation tool

From an operative perspective, Single Engine Taxi (SET) and E-Taxi techniques do not significantly differ from the traditional Double Engine Taxi (DET) procedures. Indeed, in case of SET the actors involved just need to adapt the previous standards and procedures to the use of the single engine technique. Once embedded E-Taxi solutions will be available, instead, the main differences will concern the technical features of the aircraft. On the contrary, the introduction of towing techniques involves a considerable increase in the number of vehicles running on taxiways and service roads. The safe and efficient use of these vehicles implicitly requests the redefinition of the procedures previously in force and, when needed, the introduction of new ones.

For this reason, in the long/medium planning phase, the AEON fleet management algorithm supports the operator in the estimation of the adequate number of tugs, considering the needs of a given airport (and its stakeholders) in a given period in light of its specific traffic conditions. In addition, taking into account the arrival and departure sequences and the operational constraints of the tugs fleet, this algorithm sizes the fleet of tugs needed and at the executory level can reallocate the fleet if needed.

The tug scheduling algorithm uses three inputs. As first, the tool takes into account the airport road networks, including their types and the time it takes to traverse the airport using the different networks. The second input, instead, concerns the flights schedule during a day of operation to estimate the drop-off time and corresponding energy based on a single-agent version of the path planning algorithm. Eventually, there is a list of tugs present at the airport that has to start and end their day of operations at the depot and with a full battery. From those input parameters, the tug fleet management algorithm creates a tug schedule. This schedule includes the town aircrafts, the associated tugs, and when (and where) the tugs are going to recharge. The aim of this algorithm is to maximise the environmental impact of the tugs. For this purpose, it uses a greedy search approach to determine which flights are towed. To adapt the schedule and cope with the many events that may occur – such as flight delays, tug breakdowns, or changes to the schedule because of manual preferences by the tug fleet manager – the system is based on a rolling horizon approach. When an event occurs, the input information is updated, and we reuse the allocation algorithm to re-optimize the tug schedule for the remainder of the day [12].

3.2.2.4.3 AEON multi-agent path planning tool

Secondly comes the hybrid multi-agent system (MAS). This tool computes conflict-free paths and monitors the subsequent plan execution of all aircraft and tugs moving over the airport surface concurrently. The centralized Routing Agent computes conflict-free routes for all vehicles and these are scheduled to be taxiing within a predefined planning window. This is repeated at least once per replanning period. Being on ATC side, the routing module can use confidential surveillance data. Afterwards, only the outputs, which are no longer sensitive data (routes, speed profiles and start up times) are shared with external operators. To ensure conflict-free paths, the AEON project deployed a two-level search based on Priority-Based Search (PBS) with an augmented version of the Safe Interval Path Planning (SIPP) algorithm. Once a route is cleared by ATC, the Localized Agents, in their current form, are conceptualized to be positioned at every junction. In this way, these can monitor the execution of the cleared route and trigger central replanning if the deviation exceeds time thresholds. The MAS can be utilized by the fleet allocation algorithm to obtain estimates for time and distance of paths. The MAS also interacts with the human-machine interface to facilitate co-design of the vehicle routes. In this regard, the Routing Agent takes constraints of the ATCOs into account during path planning and poses route suggestions to them. Additionally, the vehicle-specific objective functions can be adjusted to influence the path planning. These are currently based on a linear combination of taxi time and distance but may later be extended with other cost-parts. Besides that, the estimated arrival time and remaining distance per vehicle as well as the deviations during plan execution computed by the Localized Agents can be visualized in the HMI to keep stakeholders up to date [12].

3.2.2.4.4 User Interfaces and Interaction

The above-mentioned innovations have been implemented into different HMIs. These latter were designed to support three types of users with their tasks. As first comes the new role of TFM that must supervise the tug fleet allocation plan and update it according to operational events. After that there is the ground ATCOs that must control aircraft with various taxiing techniques and additional towing vehicles that will have to attach and detach from aircraft. Eventually, there are pilots that will have to follow speed targets and to turn on their engines at the most appropriate time. The envisioned position of the TFM is composed of a supervision HMI that allow to monitor the tugs' status and their allocation. This also includes a radar image which allows the spatial monitoring of all the vehicles on the apron and the taxiways, similarly to the tool used by ground ATCOs.

3.2.2.4.5 Tug Fleet Management HMI

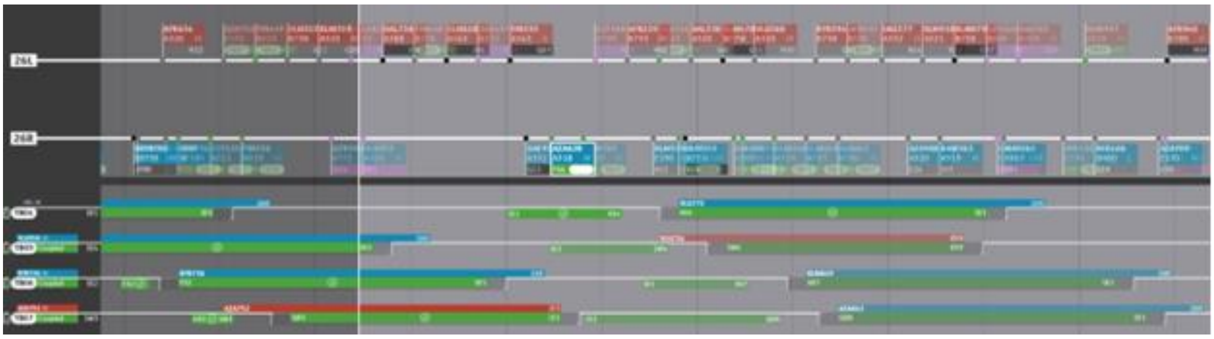

Figure 13: Supervision HMI with arriving and departing aircraft on the top and the tugs underneath with allocations.

The supervision HMI presents a synoptic view of the status of fleet of tugs and their planned allocation to departing and arriving aircraft as presented in Figure 13. The HMI shows the data through a horizontal timeline with two main panels. The top panel provides inbound and outbound flights schedule information and their expected TMO for each runway. The top area uses horizontal ribbons to present the planned departures and arrivals for each runway. All the departures and arrival items also display the taxi mode of the aircraft and in particular any tug request. The bottom panel displays allocations for each tug available to the operator. For each tug, the callsign and the battery status are displayed. Each tug is associated to a line which represents it schedule throughout the day. On each line, aircraft, and tugs allocations, expected journeys and tug unavailability duration are shown.

Although most of the allocations are computed and set by AEON algorithms using data from the A-CDM, the operator can made change via the interface to amend or cancel allocations.

3.2.2.4.6 Radar image

AEON designed a radar image presented in Figure 14 for both ATCOs and TFM. It provides situation awareness on aircraft's status, trajectory, and traffic on the airport taxiways.

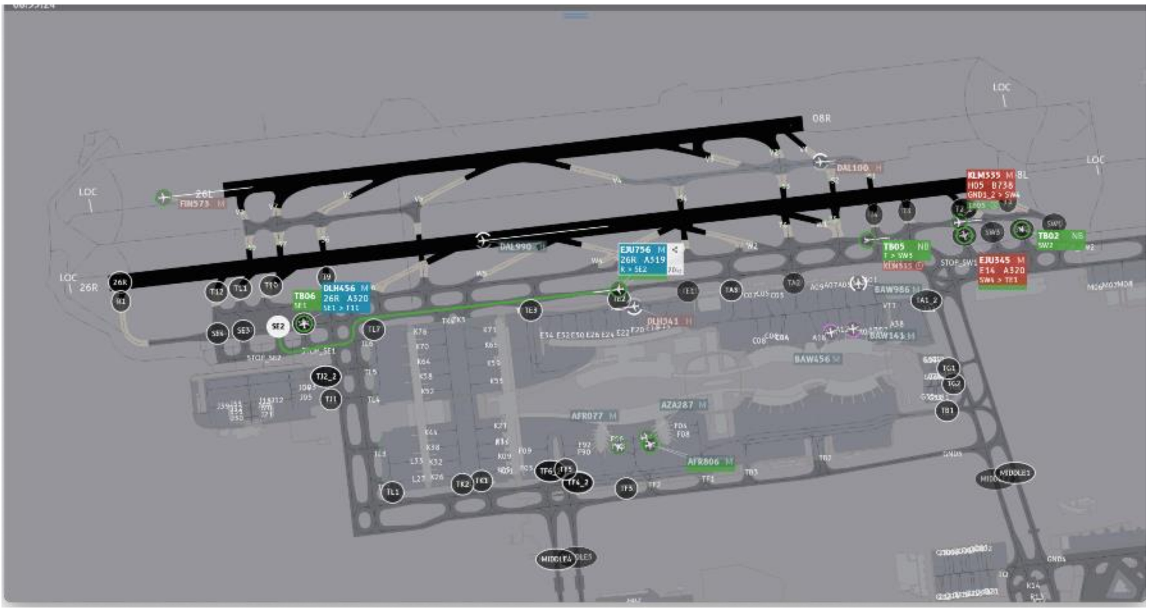

Figure 14: A-SMGCS prototype

It also provides several vehicles' characteristics and status information. This is reported in a twofold format, either textual or iconographic, and suggests paths which are computed depending on the taxi technology used by each aircraft. The flights are represented by an aircraft icon and tugs are depicted with a triangle shape surrounded by a green circle. To facilitate the identification of each tug and aircraft on the airport taxiways, information such as callsign, aircraft type, bound type, origin, and destination locations are provided on each vehicle tag. While inbound flights' tag is coloured in blue, outbound flights' is coloured in red, and tugs' tag is coloured in green. These colours were inspired by the current radar colour coding used at Paris-CDG airport. For each aircraft, the Taxi Mode of Operation (TMO) is presented as follows:

- Aircraft using all their engines are represented by 2 white semi-circles on both sides of the aircraft icon. For single SET, only a single semi-circle is visible indicating that half of the engines are off.
- Autonomous taxiing with electric engine is represented by highlighting in purple one of the 2 semi-circles at the front and rear of the aircraft icon. When the aircraft uses e-taxi techniques, the semi-circle at the front or the back is highlighted, respectively.
- Non autonomous taxiing, which necessitates aircraft to be tugged, is represented by a green dashed circle around the aircraft icon.

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To help the ATCO to visualize the optimized routes suggested by algorithms, the interface displays the corresponding route when a flight or a tug is selected. This is meant to help ATCOs identifying possible conflicts with the vehicles on other tracks. The route suggestions use the same colours than for TMO: white for classic and SET, purple for electric and green for towing. In addition, information such as advised coupling positions for an inbound flights or decoupling position for outbound flights are displayed. These different options are computed by the path planning algorithm and can be refined by the TFM. The final decision remains to the ATCO who can change a suggested route if needed before validation and clearance.

3.2.2.4.7 Moving map

Figure 15: Left: Portion of the radar image representing aircraft, their taxiing techniques, and the towing vehicles.

The moving map tool, illustrated in Figure 15, displays information on routes, speeds, and traffic awareness. It can be used inside the cockpit. The map centred on the aircraft helps pilots following the ATCO's cleared taxi route and the target taxiing speed as well as monitoring their TMO or other aircraft on the taxiways. The speed monitor instrument was designed according to Bernatzky et al. [30] recommendations on speed guidance interface for trajectory based-dispatch towing. It allows pilot to optimize their speed according to the optimal traffic configuration computed in real time by the planning algorithms, to mitigate untimely stops, gas emission and delays and to fluidify the entire airport traffic. The moving map also provides the coupling and decoupling locations and assists pilots with the engines' warmup procedure. On the cleared route, an orange segment informs the pilot where (and when) the engine should be started. This is supplemented with a starting timer which is displayed on the moving map dashboard at the relevant time. The length of the segment, and therefore the duration, is computed according to the waiting time for the runway access.

3.2.3 Differences between new and previous Operating Methods

From the descriptions of the current operating methods provided in Section 3.2.2 above, evidently, in the current scenario, the three taxiing techniques considered are mostly individually considered. On the contrary, the introduction of the AEON concept of operations implies a more systemic and coordinated approach that tends to integrate the three taxiing techniques and thus requires different and specific roles and operating methods.

The variety of engine-off taxiing techniques envisioned by the AEON project may impact current taxi operations from the long/medium planning phase of the operations to the way traffic is managed on taxiways and how aircraft navigate through airport locations. For instance, the maximum speed limit of electric taxi technologies may impact the airport ground traffic flow. Also, the integration of more tugs for towing aircraft on taxiways may intensify the already dense traffic, thus impacting controllers' and pilots' activities. However, in order to understand the AEON concept of operations and what the proposed solution is about it is important to remark that the three techniques taken into account per se are not the solution, rather how to effectively manage them to ensure further benefits and possibly overcome their limitations. AEON offers support for sizing the fleet of tugs and allocating them to specific aircraft as well as for suggesting other engine-off techniques to be used by the rest of the traffic that for a variety of different reasons may not benefit by the towing service. AEON also supports planning optimal ground traffic, through novel algorithms that suggest the best taxi trajectories for each vehicle (aircraft and tug) on the airport taxiways. Additionally, AEON provides a set of interactive tools that supports airline companies, airport service companies, airport ground controllers, tug fleet managers and pilots to perform airport taxi-related tasks, as well as the collaboration between stakeholders to optimise airport ground operations workflow.

From the comparison of current and new operating methods, several differences emerge as evident. The first and most important one is the systemic perspective that characterises the entire concept. This is the innovative aspect of the concept, but also the one that makes it quite complex and ambitious as it implies the involvement of many different actors and the interface with different tools.

Other important differences concern the following aspects of the operations:

- **Taxing techniques options –** In order to achieve the best optimised use of towing vehicles, the AO/GH and TFM are provided with real time fleet availability or internal on-board system availability (SET or e-taxi) options to be chosen and confirmed 1 hour before the departure. This is intended to enable the A-CDM platform to calculate the TSAT for the said aircraft and to define fixed coupling and decoupling points for aircraft associated to towing vehicles. This specific feature of the AEON concept is expected to largely affect the work of AO and GH.

- **Tug fleet management** - The Tug Fleet Manager (TFM) is a new role introduced in the AEON solution, whose purpose is to ensure the best availability of the vehicles fleet by monitoring their status and handling maintenance operations. It is a key role of the AEON concept of operations.

- **Taxiing path planning** – the path planning algorithm embedded in the AEON concept of operations can provide Ground ATCOs with suggestions for the more effective path planning during taxiing operations. Its introduction is expected to affect the operating methods of Ground ATCOs.

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Activities (in EATMA) that are impacted by the SESAR Solution	Current Operating Method	New Operating Method
Long-medium term planning	The A-CDM helps achieve the best optimised airside-terminal operations without considering the specific techniques used for taxiing	1. **AOs** and **GHs** are responsible of looking at the information about tugs allocation and accept/reject/change it up to 1-hour before take-off/ landing. 2. **AOs** and **GHs** shall define the taxiing techniques assigned to the rest of the traffic if not all the traffic is assigned to tugs. 3. The **AEON** HMI provides suggestions to the **TFM** for the allocation tug/aircraft Need for specific training for AOs and GHs
Tug fleet management during the execution phase	This role does not exist in current operations	1. The **AEON** HMI provides suggestions to the **TFM** for the allocation tug/aircraft and path planning for situation awareness 2. The **TFM** shall check the suggestions provided by AEON HMI. 3. The **TFM** is responsible of changing the allocation in case of delays/problems in respecting the plan Need for specific training for TFMs
Aircraft towing by tug vehicles	This role does not exist in current operations	1. The **TFM** shall communicate to **TDs** instructions about the towing vehicles allocation of each a/c. 2. The **TFM** shall communicate to **TDs planned** coupling and de-coupling points (subject to ATC modification). 3. **TDs** are responsible of promptly informing the TFM in case of delays or problems in matching the plan. 4. **TDs** receive instructions about the towing vehicles allocation of each a/c and the specific path to be followed. 5. **TDs** are also informed about coupling and de-coupling points. Need for specific training for TFMs Need for specific training for TDs

Ground and apron air traffic management	Define the taxiing path of aircraft and empty tugs, monitoring the execution of clearances	1. The **AC/GC** are in charge of providing clearances and monitor pilots and tug drivers' execution. 2. The **AEON** HMI provides to the **AC/GC** the allocation tug/aircraft and the suggested path to be followed. **3.** The **AC/GC** shall provide clearances to **PICs** and TDs. 4. The **AC/GC** is responsible of monitoring the operations, avoiding collisions and/or delays. Need for specific training for ATCOs
Taxiing	The pilots receive the clearances and speed cues to perform taxiing	**1.** **PICs** shall follow the instructions provides by the **AC/GC** (predefined path and speed profiles). 2. **PICs** are responsible of coordinating their actions with **TDs**, if needed 3. **TDs** are responsible to inform **PICs** in case of hazards on the ground. 4. **PICs** are responsible of correctly performing the operations, avoiding collisions and/or delays. Need for specific training for PICs Need for specific training for TDs

Table 6: Differences between new and previous Operating Method

4 Operational, Safety, Performance, and Interoperability Requirements (SPR-INTEROP)

The requirement's naming convention defined as follows.

The base concerns the solution and the origin of the requirement, hence all requirements in this document will start as: REQ-AEON.01-SPRINTEROP-

Then a four alphanumerical code will tell which submodule is concerned by the requirement:

- Allocation module (AM)
- Routing module (RM)
- A-CDM (CD)
- A-SMGCS (SM)
- A/C cockpit (AC)
- Tug driver (TU)
- Fleet Management (FM)
- Safety (ST)
- Organisational Safety (OR)
- Operational Safety (OP)
- E-Taxi Safety (ET)
- Interoperability (IR)
- Cost Benefit (CB)
- General (UU)

And finally, a four-digit code will be the requirement's numbering.

For instance, the first requirement dealing with the A-SMGCS will be identified as REQ-AEON.01-SPRINTEROP-SM01.0001.

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4.1 ATM operational requirements

4.1.1 Airport minimal requirements

A-SMGCS is divided into 4 services [26]:

1. Surveillance service inclues localisation and identification of mobiles
2. Airport Safety Support service adds some alerting
3. Routing service provides the ATCO with routing suggestion and allows their modification
4. Guidance service includes the communication of the clearances to pilots and vehicle drivers

PJ.04-01 defines 4 groups of airports based on several criteria and level of equipment [31]:

1. Group 1 – Full TAM Solution airports are equipped with A-CDM and DMAN, potentially an AMAN
2. Group 2 – Regional TAM Solution airports are connected to NM through A-CDM or Advanced Tower concept.
3. Group 3 – Light TAM Solution airports have a reduced traffic with some peaks.
4. Group 4 – Out of scope airports with very low traffic.

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0001
Title	AEON target airports
Requirement	Airports implementing AEON shall be group 1 or 2, equipped with an A-SMGCS with at least surveillance and routing services.
Status	In progress
Rationale	The full implementation requires routing modification (see Table 2: AEON prerequisites)
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0002
Title	Taxi techniques allocation information
Requirement	Airport that implements AEON concept shall have an access (A-CDM or another mean) to airlines information about taxi techniques planned for each aircraft to provide this information to routing services (RM).
Status	In progress

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Rationale	The full implementation requires taxi technique information (see Table 2: AEON prerequisites)
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0003
Title	Aircraft information
Requirement	An airport that implements AEON concept shall have access to aircraft information to get the level of equipment by registration.
Status	In progress
Rationale	This information is needed for the optimal computations of taxiing techniques allocation and routing.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0004
Title	Traffic information
Requirement	An airport that implements AEON concept shall have access to the inbound and out bound traffic schedule.
Status	In progress
Rationale	This information is needed for the optimal computations of taxiing techniques allocation and routing.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0006
Title	Coupling / Decoupling zone
Requirement	An airport that implements AEON concept shall have defined zones where non-autonomous taxiing aircraft can be loaded and unloaded from tug.
Status	In progress
Rationale	This information is needed for the optimal routing computations.
Category	Operational

4.1.2 Strategic long/medium planning phase requirements

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0005
Title	Ecological decision support
Requirement	ATCOs, fleet managers, pilots and tug drivers should be encouraged to take ecological actions. Indicators that measure ecological performance in real time shall be provided to all stakeholders to support strategical decisions.
Status	In Progress
Rationale	Providing ecological key performance indicators to stakeholders will increase the chances of ecological decisions when possible. During the validation sessions, the end users' feedback said that it was not relevant because it would be too long to process additional data in real time. The system shall be trusted to provide the best solution at the given time.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-CD01.0001
Title	A-CDM application taxi technique choice.
Requirement	The stakeholders shall be able in the A-CDM application to define in advance the taxi technique for each aircraft (departure and arrival). It has an impact on the TOBT and TIBT and the organisation of ground handling activities.
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-CD01.0002
Title	A-CDM application interface
Requirement	A-CDM shall use the initial tugs allocation plan computed by the Tugs allocation module in order to prefill the taxi technique choice. • Inputs: ○ Initial tugs allocation plan

	• Outputs: ○ Validated taxi technique for each aircraft
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-CD01.0003
Title	A-CDM application interface
Requirement	The stakeholders shall freeze the taxi techniques for each aircraft 1 hour before EOBT to give time for the ground handling organization.
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-AM01.0001
Title	Aircraft capacity level for tugs allocation
Requirement	Tug allocation modules shall get the information about: • Compatibility with tug towing, • E-taxi ability.
Status	In progress
Rationale	Information about compatibility with tug towing corresponds to the fact that aircraft and crew have capacities to proceed taxiing phase with a tug. Information about e-taxi ability allows to prioritize non-e-taxi aircraft for tug allocation.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-AM01.0002
Title	Tugs allocation module interface

Requirement	The tugs allocation module is in charge of defining an initial tugs allocation plan.
	• Inputs needed:
	  ○ Flight schedule (ELDT TOBT, CTOT, runway and parking)
	  ○ Number of available tugs
	  ○ List of eligible aircrafts
	• Outputs:
	  ○ Initial tugs allocation plan
	The output is directed to the A-CDM application that may use it to instantiate the choice of taxi techniques for the aircraft that can be towed.

Status	In progress
Rationale	The algorithm module needs inputs to compute the allocation plan
Category	Interoperability

4.1.3 Execution phase requirements

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0001
Title	Green routing suggestion
Requirement	The A-SMGCS routing service shall provide ATCO with the greener computed route suggestion, available at the time, for a given vehicle (aircraft or tug) upon request.
Status	In progress
Rationale	ATCO needs a quick suggestion to handle the operations in real time
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0002
Title	A- SMGCS application interactions
Requirement	The A- SMGCS radar image shall provide feedback for the ATCO:

	• Actual speed or speed tendency of vehicles • Future routes of vehicles (aircraft and tugs).
Status	In progress
Rationale	It will help ATCO decision making process
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0005
Title	ATCO situation awareness
Requirement	Radar image vehicles labels shall be completed with taxi information, for instance a dedicated colour code and specific icons.
Status	In progress
Rationale	ATCO needs a complete situation awareness about current traffic taxiing options. Each taxi technique implies its own constraints (dynamic performances, specific routing for towed aircraft…).
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0006
Title	ATCO situation awareness
Requirement	For towed aircraft, the A-SMGCS radar image could display the coupling/decoupling status information.
Status	In progress
Rationale	ATCO needs a complete situation awareness about current traffic taxiing options. However, this feature would require a new information digitally exchanged between aircraft or tug and A-SMGCS system.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-AC01.0001
Title	Communication of AEON recommendations

Requirement	Unless any urgent situation requires immediate action, any AEON recommendation (such as speed profile and optimal engine warming procedure start) shall not be communicated on aerodrome frequencies.
Status	In progress
Rationale	Aerodrome frequencies may be overcrowded and should be kept for clearance requests and deliveries. Recommendations shall be communicated via other unintrusive means.
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0001
Title	Functionality of routing module
Requirement	The routing module shall provide conflict-free path planning of all aircraft and tugs moving along taxiway centrelines. The best route suggestion available is provided upon request, the routing module will update the result according to current situation from surveillance data.
Status	In progress
Rationale	The speed profiles could be used as means to anticipate and solve conflicts along the routes and yield the benefit of less full stops required to de-conflict aircraft and/or tugs on taxiways as well as more accurate taxi time and distance predictions. Conflict-free path planning remains valid under the condition that the underlying speed profiles along the routes are followed accurately by pilots and tug-drivers. Having a centralised routing module allows it to use surveillance data without security issue.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0002
Title	Calculation of routes
Requirement	Routing module shall take into account ATCOs input parameters in order to influence the default routing / speed profile calculation (high-level routing parameters such as avoidance level of non-standard taxiway directions as well as priority considerations like prioritization level of inbound vs. outbound flights or tugs in comparison to aircraft).

Status	In progress
Rationale	This allows an ATCO to adjust the default routing to obtain suggestions that match his/her preferences or working principles better. Routing manual takes operational procedures as input.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0004
Title	Modifying routing parameters in the HMI
Requirement	The A-SMGCS radar image shall allow ATCOs to influence the default routing calculation by setting constraints via waypoints.
Status	In progress
Rationale	This allows an ATCO to adjust the default routing to obtain suggestions that match his/her preferences or working principles better.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0003
Title	Aircraft equipment level for routing
Requirement	Routing module shall get the information of the taxiing technique chosen for each aircraft up to 1 hour before TOBT
Status	In progress
Rationale	The selected taxiing technique influences the kinematic values used for routing and thus the traversal times along the segments of the taxiway network. The latter are needed to provide conflict-free path planning of the concurrent routes of all aircraft and tugs.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0004
Title	Routing module interface input
Requirement	The routing module shall get the following information as basis for the route calculations:

	• flight schedule including TLDT or TOBT, CTOT, default gate and runway locations (can be based on a set of possible locations, e.g., viable runway entries), usable taxiing techniques, assigned taxiing technique • Airport map constraints (operational procedures, coupling/decoupling areas, engines safe start up zones) • task assignments of tugs from tug allocation module • vehicle properties of all aircraft and tugs, e.g., length, width/wingspan, distance needed for landing / take-off, etc. as well as kinematic values, i.e., maximal velocity, reduced velocity for turns together with corresponding radius of curvature for which this is applicable, fixed acceleration / deceleration rates per vehicle type • process times: e.g., coupling / decoupling time, engine-start time, time for switching direction (e.g., in case of pushback) • cleared path: once a route is (partially) cleared, its cleared path shall be provided to the routing module. Runway assignment in the flight schedule shall match the runway mode of operation (RMO, defining active vs. inactive runways)
Status	In progress
Rationale	Definition of the routing module API
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0008
Title	Routing module interface output
Requirement	The routing module shall provide: • route suggestions • speed profiles • accurate taxi time estimations • engine start-up times as key enabler for the Guidance Service of the A-SMGCS.
Status	Interoperability

Rationale	Definition of the routing module API
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0005
Title	Changing information
Requirement	The routing module shall be notified and receive any changes to the flight schedule, the RMO, or the tug assignment.
Status	In progress
Rationale	The routing can only be reliably done if the data used in it is up to date
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0006
Title	Position and speed tracking of all aircraft and tugs for Routing Module
Requirement	The routing module shall have access to current position and speed data of all aircraft and tugs.
Status	In progress
Rationale	This is necessary to allow for tracking of plan execution of all aircraft and tugs and to calculate the corresponding deviations to the planned paths. This enables path re-planning in case of substantial deviations.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0009
Title	Non autonomous specific routing
Requirement	Towed aircraft shall be routed to coupling/decoupling locations
Status	In progress
Rationale	This impacts the route suggestion to be displayed on A-SMGCS radar image.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0007
Title	Path re-planning
Requirement	The routing module shall perform path re-planning when the plan executed by pilots or tugs deviates substantially from the plan.
Status	In progress
Rationale	Otherwise, conflict-free routes can no longer be guaranteed, since deviations between path planning and plan execution may result in newly appearing conflicts that would have to be resolved manually, possibly leading to a further increase in delays.
Category	Operational

4.1.3.1 Manage & Execute tugs driving

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0001
Title	Tugs fleet monitoring role
Requirement	A fleet manager shall be appointed for any airport that exploits (semi-) autonomous tugs simultaneously.
Status	In progress
Rationale	This will allow the monitoring of AEON optimisation plan execution and provide awareness on plan deviations which will be resolved immediately.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0006
Title	Tugs fleet Manager number
Requirement	Depending on the economic model (i.e., who provides the non-autonomous taxiing service) and the traffic size, several Tug Fleet Managers shall be necessary.
Status	In progress
Rationale	Although it has not been evaluated in the scope of AEON, the role has been designed to be scalable without additional coordination needed. The TFM communicates with its own tugs drivers and not directly with ATCO.
Category	Operational

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Identifier	REQ-AEON.01-SPRINTEROP-FM01.0002
Title	Tugs fleet monitoring responsibilities
Requirement	Tugs fleet manager shall be able to monitor whole tug fleet and tugs allocations to ensure that the allocation plan is going according to schedule and manage potential schedule deviations.
Status	In progress
Rationale	Tug allocation information will support operators in planning for and managing situations that will impact efficiency of ground traffic.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0003
Title	Tug allocation
Requirement	Tug fleet managers shall be able to allocate or reallocate appropriate tugs to appropriate aircrafts for taxi when the operator needs it. The allocation should support fuel saving. When possible, Tug drivers should be aware of their tug allocation schedule so they can anticipate routes throughout the day.
Status	In progress
Rationale	In case the current traffic situation deviates from the scheduled traffic plan, tugs will need to be reallocated to ensure safety and optimal capacity until the traffic situation returns to the scheduled plan.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0007
Title	Tug allocation
Requirement	Means to cancel planned allocation and to manually allocate tug to aircrafts shall be provided.
Status	In progress
Rationale	In case the current traffic situation deviates from the scheduled traffic plan, tugs will need to be reallocated to ensure safety and optimal capacity until the traffic situation returns to the scheduled plan.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0004
Title	Tugs fleet situation awareness
Requirement	Tug fleet manager shall be able to have a complete situation awareness about current traffic with a radar image. In addition, TFM could listen to ATC radio frequency).
Status	In progress
Rationale	Tug allocation information will support operators in planning for and managing situations that will impact efficiency of ground traffic.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0007
Title	Towable aircraft awareness
Requirement	Tug fleet manager shall be able to identify on the HMIs which aircraft can be towed or not.
Status	In progress
Rationale	In case of reallocation, towing could be proposed to an aircraft that was not initially planned. E-Taxi aircraft would then be avoided.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0005
Title	Mission status information from Tug Drivers
Requirement	Tug fleet managers shall be informed about missions performed by tugs according to ATCO's clearances.
Status	In progress
Rationale	In case the current traffic situation deviates from the scheduled traffic plan, tugs will need to be reallocated to ensure safety and optimal capacity until the traffic situation returns to the scheduled plan.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0001

Title	Tug driving support / Routings for tug drivers
Requirement	Tug drivers shall be able to optimise the traffic performance by complying with the traffic optimisation rules. Regulations such as planned route and expected driving speed, and real time contextual traffic information to ensure high driving performance shall be provided.
Status	In progress
Rationale	Providing tug's mission information and real time tugs behaviour information to drivers/pilots will provide means to ensure that the rules optimising the traffic performance are being followed.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0008
Title	Routes display for tug drivers
Requirement	Tugs drivers shall be able to visualise the routing clearance and the suggested speed profile.
Status	In progress
Rationale	Providing tug's mission information and real time tugs behaviour information to drivers/pilots will provide means to ensure that the rules optimising the traffic performance are being followed.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0002
Title	Human-driven tugs commands takeover support
Requirement	Drivers and pilots shall be aware of when they have the control of the tug. Hence, information on when the tug drivers and pilots should give the control back should be provided. This will also provide information on when the coupling and uncoupling procedures between the aircraft and the tug should be initiated.
Status	In progress
Rationale	In AEON, tugs will be driven by tug drivers when no aircraft is being towed or pilots when the aircraft is being towed. Providing information about coupling and uncoupling procedures, and control takeovers will ensure the maximisation of aircraft engine off navigation duration.

Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0007
Title	Coordination requests to ATCOs
Requirement	Tug drivers shall communicate with ATCOs as current ground vehicles for requests and clearances to move (not like aircraft). Tug drivers could communicate with ATCOs via datalink.
Status	In progress
Rationale	Radio communications are already overloaded, and additional tugs underground ATCO supervision will add exchanges. Specific phraseology is needed to clearly differentiate exchanges with tug drivers from exchanges with pilots. Digital communications shall be envisaged.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0005
Title	Coordination requests to tug drivers
Requirement	Tug drivers and pilots must be reachable by ATCO to allow immediate changes to reroute traffic when necessary. Synchronous request that will enable coordination between stakeholders and tugs drivers / pilots should be provided.
Status	In progress
Rationale	To ensure optimal traffic flow, communicating with tugs drivers synchronously is necessary. For instance, immediate requests which include holding points, crossing sequence, or deviation from initial route among others requires immediate acknowledgement to ensure traffic safety.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0006

Title	Tugs maintenance support
Requirement	The tug fleet manager shall be aware of any maintenance operation required on the tugs. The maintenance operations could include fuelling, repair, or check-ups. If the maintenance operation does not require long immobilisation (such as fuelling), the location and the timing to perform the maintenance operation should be provided.
Status	In progress
Rationale	Providing information on tugs maintenance will allow to plan maintenance operations ahead and keep the traffic performance high.
Category	Operational

4.1.3.2 Manage & Execute aircraft taxiing

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0007
Title	A-SMGCS radar image interface modification
Requirement	The A-SMGCS radar image needs the following additional inputs: • Taxi technique equipment per aircraft • Taxi technique choice for each aircraft
Status	In progress
Rationale	This requirement only lists additional information exchanges for AEON implementation
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0003
Title	A- SMGCS digital output
Requirement	The A-SMGCS radar image uses the new routing suggestion provided by the routing module, which provides also the optimal engines start up time. This information, together with remaining taxi time shall be digitally sent to a cockpit system (EFB, moving map …).
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.

Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0008
Title	A- SMGCS airport map
Requirement	The airport information map shall include safe engines start up zones and coupling/decoupling areas.
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-AC01.0002
Title	Routing for pilots
Requirement	The pilot shall be able to visualise the routing clearance and the suggested speed profile. The pilot will be responsible to follow the suggestions; the ATCO will adapt the next clearances accordingly.
Status	In progress
Rationale	This requirement shall be kept in consideration in further stages of the research in this area.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-AC01.0003
Title	Aircraft engines start support
Requirement	Pilots shall be aware of the optimal area / time where / when the aircraft engines should be started.
Status	In progress
Rationale	Starting the engines at the right time / location can minimise queuing at runways while maximising the duration of engine off navigation
Category	Operational

4.2 Safety requirements

In this section, we will consider the most prominent safety hazards and safety requirements for tug-enabled aircraft towing and e-taxi. Note that Single Engine Taxiing is already in use by many airlines at different airports, for which detailed operations manuals including safety requirements are written and used by these airlines. Since this is not novel, we won't provide safety analysis and requirements for Single Engine Taxiing, but rather focus on tug-enabled taxiing and e-taxi.

Safety risks are usually characterized using a risk assessment matrix, such as depicted in Figure 16, which we will also use.

Risk probability	Risk severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely improbable 1	1A	1B	1C	1D	1E

Figure 16: Risk assessment matrix

4.2.1 Safety hazards and requirements for tug-enabled aircraft towing

Safety hazards for tug-enabled aircraft towing

We divide all safety hazards into four categories: mechanical, electric, psychological strain, perception- and organization-related safety events, which are in line with TaxiBot Operational Concept Manual [32].

The most prominent *mechanical safety hazards* of tug-enabled aircraft towing include:

- bruising of tug drivers, e.g., when coupling tugs and aircraft or connecting tow rods, or while standing between aircraft and the tug (risk category 1D)
- bumping of a tug into wings, antennas, driver cabin, gear doors, gear struts (2B)
- colliding of a tug with other ground units (2D)
- ground personnel being hit by a tug (2D)
- an aircraft/tug being hit being hit by a towing rod, e.g., resulting from unintentional loosening of the coupling at tug or aircraft, steering movements of the nose landing gear with coupled towing bar (1D)
- excessive nose landing gear fatigue (3C)

- jet engine blast during engine start-up on other aircraft taxiing behind (2C)
- weather-related slipperiness of a tug (3C)
- the aircraft engine being on during tug coupling and decoupling operations

The most prominent *electric safety hazards* of tug-enabled aircraft towing include:

- damaged isolation of cables, housings, and defective connector systems (1D)
- electrostatic discharge, e.g., during storms (1E)
- battery short circuit, resulting into fire (1B)

The most prominent *psychological strain safety hazards* of tug-enabled aircraft towing include:

- stress caused by time pressure, high workload, and external traffic such as intense traffic (2C)

The most prominent *perception- and organization-related safety hazards* of tug-enabled aircraft towing include:

- limited observation possibilities of a tug driver under certain weather conditions, e.g., of the tug's state, the state of aircraft (engines), other moving units and people, obstacles.
- miscommunication/lack of coordination between a tug driver and a pilot during the handover of control over the tug movement, directly after pushback
- miscommunication/lack of coordination between a tug driver and a pilot in the process of uncoupling
- miscommunication/lack of coordination between a tug driver and other ground personnel during coupling

Safety requirements for tug-enabled aircraft towing

The safety requirements are divided into technical, organisational, and operational safety requirements.

Technical safety requirements:

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0001
Title	Tug lighting
Requirement	Tug shall have light during darkness
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0005
Title	Optical and acoustic warning devices

Requirement	Optical and acoustic warning devices should be used to prevent collisions of tugs with other ground vehicles and aircraft
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0006
Title	Maintenance of towing lines and marked areas
Requirement	The airport shall maintain towing lines and marked areas
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety
Identifier	REQ-AEON.01-SPRINTEROP-ST01.0007
Title	Maintenance of towing lines and marked areas
Requirement	Tug drivers and pilots shall establish and control interlocking coupling safety mechanisms at tug and aircraft
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0008
Title	Correspondence between tugs and aircraft types
Requirement	Tug fleet manager and tug drivers shall use tugs and the associated with them equipment authorized for the corresponding aircraft type
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0009
Title	Anti-sleep sheets for tugs
Requirement	The airport shall put anti-sleep sheets in tug entrance and exit areas (if service roads are used)
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Organisational safety requirements:

Identifier	REQ-AEON.01-SPRINTEROP-OR01.0001
Title	Pilot training to operate tugs
Requirement	Airlines together with airports shall train pilots to operate tugs
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OR01.0002
Title	Tug driver training
Requirement	Airports and ground handlers shall train tug drivers to operate tugs with different aircraft
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OR01.0003
Title	Emergency procedures
Requirement	The airport shall develop emergency procedures for tug-enabled taxiing

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Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OR01.0004
Title	Training tug drivers to move in and out hangars
Requirement	The airport shall train tug drivers to moving into and out of hangars
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Operational safety requirements:

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0001
Title	Compliance with manufacturer documents and safety instructions
Requirement	Tug drivers and pilots shall comply with manufacturer documents and safety instructions
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0002
Title	Workload of tug drivers
Requirement	Tug fleet manager shall coordinate workload of the tug drivers
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0003
Title	Ensuring safety separation distances
Requirement	Tug drivers and pilots shall comply with safety (separation) distances
Status	In progress
Rationale	Directly related to the identified safety hazards The separation distances are defined in accordance with the ICAO regulations depending on the aircraft type and the mode of taxiing [44].
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0004
Title	Monitoring of surroundings by tug drivers
Requirement	Tug drivers shall observe their surroundings attentively
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0005
Title	Unambiguous communication between cockpit and tug drivers
Requirement	Cockpit, tug drivers, TFM and ATCo shall communicate with each other unambiguously
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0006
Title	No person located between aircraft and a tug
Requirement	Pilots and tug drivers shall make sure that there is no person located between aircraft and a tug

Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0007
Title	Maximum speed of the aircraft-tug combination
Requirement	Pilots and tug drivers shall comply with the maximum speed of the aircraft-tug combination, which depends on the taxiway conditions and the airport regulations
Status	In progress
Rationale	Identified in the discussion with experts
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0008
Title	Hydraulic system is on when a tug is attached
Requirement	Pilots shall ensure that the hydraulics is switched on when a tug is connected to the aircraft to make steering of aircraft nose gear possible
Status	In progress
Rationale	Identified in the discussion with experts
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0009
Title	Tug and aircraft compatibility
Requirement	Before pushback and taxi operations tug driver shall ensure that the data entered to their tug's computer about the connected aircraft is correct
Status	In progress
Rationale	Identified in the discussion with experts
Category	Safety

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Identifier	REQ-AEON.01-SPRINTEROP-OP01.0010
Title	Compliance with the right-of-way rules
Requirement	All stakeholders involved in the airport surface movement operations shall comply with clearly defined right-of-way rules
Status	In progress
Rationale	Identified in the discussion with experts
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-OP01.0011
Title	Pilots minding attached tugs
Requirement	Pilots shall pay special attention to the location of tugs attached to their aircraft in order not to collide with any object and not to trespass any protected area
Status	In progress
Rationale	Identified in the discussion with experts
Category	Safety

4.2.2 Safety hazards and requirements for e-taxi

Safety hazards:

- Low pilot’s visibility of the surrounding area during pushback
- Clutch failure

Safety requirements:

Identifier	REQ-AEON.01-SPRINTEROP-ET01.0001
Title	Improving pilot’s situation awareness during pushback
Requirement	The airport/airline should install a 360-degree view camera system which will enable a wider visibility to improve pilot’s situation awareness during pushback.
Status	In progress
Rationale	Directly related to the identified safety hazards

Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ET01.0002
Title	Replacing the clutch system to allow both rotational and axial movements
Requirement	The aircraft manufacturer should replace the clutch system with mechanisms which shape and geometry permit both rotational and axial movements
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

4.2.3 Safety hazards and requirements for single engine taxiing

Safety hazards:

- loss of braking capability and nose wheel steering while taxiing on uphill slopes or slippery surfaces.

- jet blast, especially of wide-body aircraft.

Identifier	REQ-AEON.01-SPRINTEROP-SE01.0001
Title	Restrictions on using single-engine taxiing
Requirement	The pilots shall avoid using single-engine taxiing for uphill slopes and slippery surfaces, and when sharp taxiway turns should be taken.
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-SE01.0002
Title	Maintain an adequate safety distance with a SET aircraft
Requirement	All actors should maintain an adequate safety distance with a SET aircraft to avoid jet blast

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Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Additional safety requirements but not related to ATM are listed in Appendix A.

4.3 Benefits assessment

Candidate solutions [45]	KPAs [7]	KPIs	Impact [8][9][10]	Comment
Tug Fleet Manager role	**Human Performance**	Workload	↔	The new TFM figure increases the controller's coordination tasks and consequently his workload; however, this remains at acceptable levels. On a systemic level, it is assumed that the general workload associated with the management of taxiing operations may be decreased - further studies are needed to verify this.
		Situation Awareness	↑	The introduction of the TFM and related tools increases overall situational awareness with respect to the management of taxiing operations.
	Liability	Risk of negligence or carelessness	↔	The way the new role was defined contribute to keep the risk of negligence and carelessness stable.
	Safety	Runway incursions	**N/A**	Unintended runway incursion by a tug, when pilot, because of the lack of visibility, would stop the aircraft too late at the runway holding point and the tug would appear at the protected area of the runway.
		Safety separation distances	↑	Separations should be maintained thanks to the supervision of the TFM – further studies are needed to verify this.
		Unambiguous communication	↓	Because of additional drivers on R/T and potential clearances mix
	Cost Benefit	Fuel consumption	↓	The TFM and supporting tools are expected to provide optimal allocation of each technique, decreasing fuel consumption.

	Capacity	Taxi-out additional time	↓	The new role is expected to optimise outbound flow.
		Airport peak capacity	↔	
		Airport peak throughput	↓	To be confirmed with fast time simulations
		Taxi-in additional time	↔	
	Efficiency	Departure punctuality	↔	
		Airport throughput efficiency	↓	To be confirmed with fast time simulations
		Arrival punctuality	↔	
	Environment	Fuel consumption (and emissions)	↓	The introduction of the TFM and related tools enhance the management of taxiing operations decreasing fuel consumption.
		Ecological decision support	↑	The introduction of the TFM and related tools enhance the ecological decision-making process.
		Green routing suggestion	↑	
ATC centralised routing module	**Human Performance**	Workload	↓	Optimised routing suggestions are expected to decrease ATCO's workload.
		Situation Awareness	↑	Optimised routing suggestions are expected to increase ATCO's situation awareness.
	Liability	Risk of negligence or carelessness	↔	Relevant routing suggestions using operational procedures contribute to keep the risk of negligence and carelessness stable.
	Safety	Runway incursions	↓	The provided suggestions are expected to decrease the risk of

				runway incursions through improved HMI.
		Safety separation distances	↑	Thanks to the speed profiles and path allocation
		Unambiguous communication	↔	Thanks to the speed profiles and path allocation
	Cost Benefit	Fuel consumption	↓	Speed profiles and path allocation decreases fuel consumption
	Capacity	Taxi-out additional time	↓	Thanks to optimised routing of all vehicles
		Airport peak capacity	↔	Thanks to optimised routing of all vehicles
		Airport peak throughput	↔	
		Taxi-in additional time	↓	Thanks to optimised routing of all vehicles
	Efficiency	Departure punctuality	↑	Thanks to optimised routing of all vehicles
		Airport throughput efficiency	↑	Thanks to optimised routing of all vehicles
		Arrival punctuality	↑	Thanks to optimised routing of all vehicles
	Environment	Fuel consumption (and emissions)	↓	Speed profiles and path allocation decreases fuel consumption and therefore emissions.
		Ecological decision support	↑	Speed profiles and path suggestions support the ecological decision-making process of ATOCs.
		Green routing suggestion	↑	

Table 7: Candidate solutions benefit assessment

4.4 Interoperability requirements

As the size and weight of aircraft vary a lot, from 40 tonnes for an Embraer 170 to 550 tonnes for an A380, it is technically difficult and most likely not very cost effective to have a single towing vehicle that can handle all aircraft types and multiple different vehicles with different sizes and capacities will be required. A truck which can tow larger aircraft might also not fit under smaller aircraft, due to required weight and volume requirements. It would also be not very cost effective to use a more expensive truck, unless that truck would be unused otherwise.

There might still be overlap between the different vehicles with respect to the aircraft types they can handle, as well as the components of the vehicles such as battery packs. An A321 neo could for instance be towed by a truck than can tow medium range narrow bodies, such as the 737 and A320 family, but also by a truck designed for smaller wide bodies, such as the A330 or a B767 as long as the larger truck is low enough. Also, a truck designed for regional jets as the A220 and E-170/E-190 family can probably tow a A320, but at reduced speed due to limited traction and power available, which can be acceptable for smaller taxi distances. This would allow more flexibility with respect to planning, which can be especially useful as the size of aircraft often varies a lot throughout the day at most larger airports.

In any case, it is suggested to create a table of aircraft types vs. tow truck design to indicate the level of compatibility between the two, so this can be taken into account in the planning.

For autonomous e-taxi, each aircraft type will also need a system mostly custom made to its size and weight, including modifications to the power supply / APU. This can be in the number of powered wheels for traction as well as the number electric motors and the electrical power per electric motor. Again, here there can be commonality between different installations.

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0001
Title	Compatibility Tug
Requirement	The AEON solution shall be compatible with and certified for respective aircraft type with regard to both weight and size
Status	In progress
Rationale	A tug should have enough torque and power and should fit underneath each aircraft type can be assigned to and tow it at an acceptable speed.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0002
Title	Compatibility e-Taxi
Requirement	The AEON solution shall be compatible with respective aircraft type it is installed on.

Status	In progress
Rationale	An e-Taxi system must also be compatible with an aircraft it is integrated into and able to provide enough torque and power to move the aircraft at acceptable taxi speeds.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0003
Title	CNS Interoperability for communication
Requirement	CPDLC shall allow the communication of routing information, speed profile and engine start-up time
Status	In progress
Rationale	Pilots need the information to optimally manage ecological taxiing.
Category	Operational

AEON solution would potentially impact several A-SMGCS services:

- Surveillance service:
    - Additional tugs to be equipped with transponders
    - Tugs and Towed aircraft to be displayed on radar image
    - Additional tugs on radio frequency
    - Additional 'flight plan' data with the taxiing technique
    - A-SMGCS data may be used for external services such as Tug Fleet Manager working position
    - New statistics on ecological taxiing indicator
- Airport Safety Support Service:
    - Tugs on taxiway are more maneuvrable, impact on the conflicts detection system
    - Differences in aircraft dynamics may impact CMAC alerting system
- Routing Service:
    - Routing dependent on taxi technique
    - New speed profiles computation

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    - Taxi time computation dependent on taxi technique

- Guidance Service :
    - Additional vehicles to guide
    - Additional data to transfer to vehicles (speed profiles)
    - Extended use of datalink for non critical clearances (frequency transfer…)

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0004
Title	A-CDM Interoperability for taxi technique
Requirement	The taxi technique for each aircraft shall be communicated from A-CDM to A-SMGCS system
Status	In progress
Rationale	The taxi technique influences the routing and the dynamics of the aircraft
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0005
Title	A-CDM Interoperability for taxi time
Requirement	The variable taxi time computed for each aircraft shall be communicated from A-SMGCS to A-CDM system
Status	In progress
Rationale	Variable taxi time refined with taxi technique is used in TOBT and TIBT computation
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-IR01.0006
Title	Tugs loading/unloading progress
Requirement	Tugs should be able to send information on the (un)loading process progression to A-SMGCS
Status	In progress

Rationale	This information would increase ATCO situational awareness if it could be displayed on A-SMGCS radar image
Category	Operational

Solution PJ.04–W2–29.3 seeks to introduce an element of environmental impact assessment in the overall airport operations performance management, thereby influencing operational decisions in the pre-tactical and tactical phases, introducing a pro-active management approach rather than a reactive one. The inclusion of Environmental Performance Management is through two high-level parameters, namely noise and emissions. Specific indicators relating to these high-level parameters are assessed as part of an overall performance framework (i.e. goals, targets, rules, thresholds, trade-off criteria and priorities) in both the planning and execution operations phases. In this definition, AEON is compatible with Solution PJ.04–W2–29.3 at pre-tactical phase with the tug allocation module and at tactical phase with the Tug Fleet Manager working opposition and when the routing module would be able to provide noxious emission estimates for instance

4.5 Cost & Benefit

Cost and benefit assessment outlines the main ideas and core principles to explore the benefits and requirements of non-engine taxiing before using towing vehicles or autonomous e-Taxi. This section presents some initial considerations about possible costs and benefits associated to the operational concept outlined in the document, that will be further extended in D5.4 [10]. The intended audience of the assessment includes ground handlers, airport management, airlines, ATC operators, the industry providing green taxiing solutions, and the overall aviation community.

In the assessment, the main interests are the costs and benefits of alternative taxi systems, fuel savings, tow trucks required for implementing towing at the largest European airports, impact of decoupling operations of towing vehicles, evaluation of autonomous e-Taxi system for the largest European airlines.

The benefits of using non-engine taxiing should be higher than the costs. The costs of non-engine taxiing operations will generally be covered by the airline, directly or indirectly. Costs can generally be divided into investment costs and operational costs. Tow trucks can be bought or rented. In any case, all capital cost will have to be converted to a daily or yearly costs using a depreciation rate. Potential costs are related to changes in infrastructure, aircraft modifications, equipment, energy, staff and delays. The main benefits are cost savings due to decreased fuel consumption and less maintenance, positive impact on environment.

To assess the cost vs. benefit of the system, the time at which different costs and benefits are made plays an important role. While some costs are made during the actual operation such as tire wear and electricity of diesel usage, cost for research and development are made many years in advance. While the largest benefit, reduced fuel consumption, is during the operation, long term benefits (such as environmental impact) also exist.

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Cost and benefit assessment for towing operations includes the evaluation of fuel costs and environmental impact of using towing vehicles in taxiing operations. Furthermore, use of towing vehicles might require changes in airport infrastructure such as allocating spaces for decoupling operations close to the runways. These operations create new chains of tasks in outbound process. While allocating additional decoupling locations reduce cycle times, indirect costs of not using the allocated spaces for other tasks might occur. Utilization of the system plays a key role in determining the number of decoupling locations at strategical level and the indirect costs and benefits of the changes in airport infrastructure are highly affected by the way the system is designed. Therefore, another aspect of the assessment is the analysis of system performance of introducing new tasks for decoupling towing vehicles in outbound process and allocating new spaces.

For autonomous e-Taxi the main benefit is the fuel saved during taxi, for which large airports with longest taxi times would have the largest benefit. The main costs are the costs of installing the system on an aircraft, as well as increased fuel consumption in flight due to the additional weight of the electric motors and the rest of the system.

For practical purposes, it is suggested to split the costs in three categories, yearly costs, daily cost and costs per operations.

Yearly costs are the costs for owning a vehicle. These include the depreciation of towing vehicles and support equipment. Especially towing vehicles are mobile and could be sold or bough on a yearly basis. With support equipment, such as charging stations, this is much more difficulty. It is also assumed that research and development and support costs are included in the yearly costs for each vehicle. There might be an option for subsidies, which will then probably be used to offset the development and depreciation costs. Daily costs are mostly staff related costs and only applicable to two trucks. Especially if a truck driver must be present in the vehicle, then he must be paid even if the truck is only used once that day.

Costs per operation are mostly energy and maintenance related. The more we use a vehicle, the more energy it will use, and the more wear will be. The cost may vary, depending on the operation.

For the financial benefit, it is assumed that this is initially purely on a per operation basis. Each time an aircraft is towed, this will lead to a saving in fuel, shown in Figure 17, and maintenance costs.

For autonomous taxi, there is a yearly cost for the installation of the system and additional fuel is used per operation due to the added weight, resulting in a marginal saving, illustrated in Figure 18. There is no direct daily cost, and the benefit is mostly identical for towing.

For towing, each extra towing vehicle added to the fleet will lead to an additional number of flights being towed, leading to a marginal savings in fuel consumption, as illustrated in Figure 19.

Each towed aircraft potentially joins a queue in front of decoupling locations before heading to runway. Depending on the frequency of towed aircraft arriving to decoupling locations and durations of decoupling operations at decoupling points, delays in take-offs and increase in queues of towed aircraft at the airport might be observed. Design of allocation and number of allocated spaces are critical in reducing queues and waiting times. A careful analysis is required at strategical level since allocating new spaces can have conflicting effects. The allocated spaces could either be used in reducing queue sizes at peak times or remain idle when flight schedules are loose. Thus, utilization versus queue sizes should be evaluated using queueing models for different prospective scenarios before deciding to use towing vehicles and allocating spaces for decoupling operations.

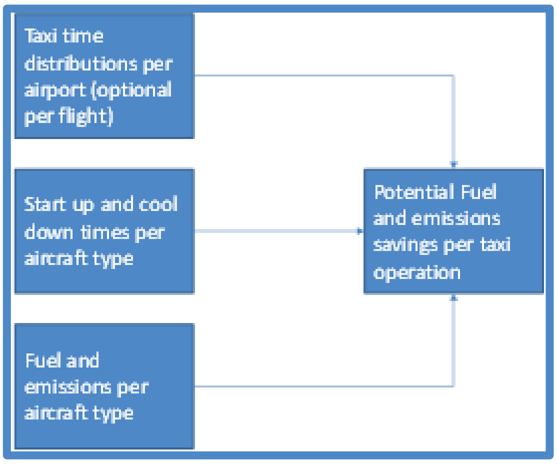


Figure 17: Taxi fuel saving per operation

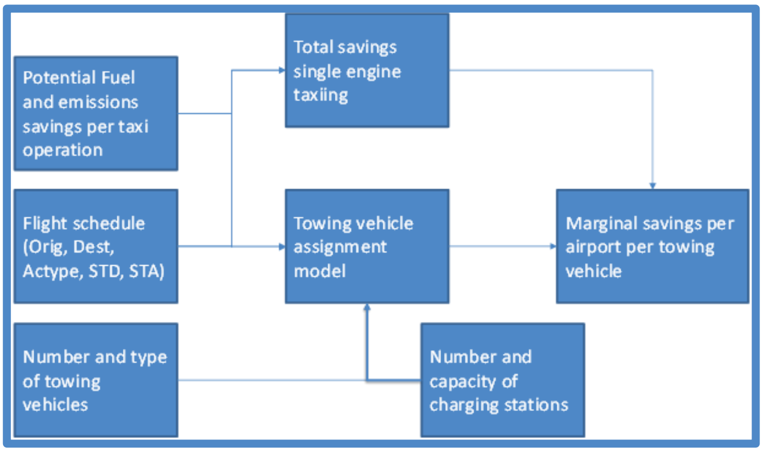
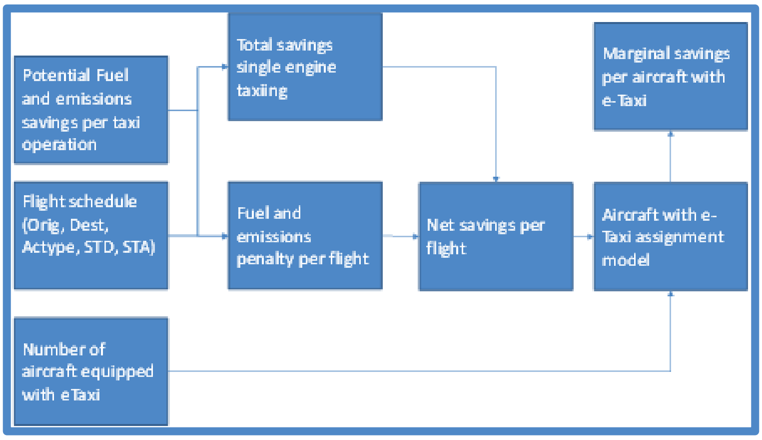


Figure 18: Fuel saving for autonomous e-Taxi



5 References

[1] AEON, D1.3 'State of the Art'

[2] Deonandan, I. and Balakrishnan, H. 2010. Evaluation of strategies for reducing taxi-out emissions at airports. 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference (2010), 9370.

[3] Stettler, M.E.J., Eastham, S. and Barrett, S.R.H. 2011. Air quality and public health impacts of UK airports. Part I: Emissions. Atmospheric environment. 45, 31 (2011), 5415–5424.

[4] Lukic, M., Hebala, A., Giangrande, P., Klumpner, C., Nuzzo, S., Chen, G., Gerada, C., Eastwick, C. and Galea, M. 2018. State of the art of electric taxiing systems. 2018 IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC) (2018), 1–6.

[5] Greener Aircraft Taxiing: Single-Engine Taxi-out Evaluations: https://www.sesarju.eu/sites/default/files/documents/webinars/Guiseppe.pdf.

[6] AEON, D1.1 Concept of Operations Initial Version.

[7] AEON, D5.1 Solution Assessment Plan

[8] AEON, D5.2 HP Assessment Report [the document will be available online at this link]

[9] AEON, D5.3 Safety Assessment Report [the document will be available online at this link]

[10] AEON, D5.4 Cost Assessment [the document will be available online at this link]

[11] AEON, D2.1 Multi-Agent System for Routing [the document will be available online at this link]

[12] AEON, D2.2 Model for optimal allocation of towing vehicles [the document will be available online at this link]

[13] AEON, D3.1 Representative use cases.

[14] AEON, D3.2 Supervision HMI and interactions.

[15] AEON, D4.2 Description of the final validation platform.

[16] European Parliament, *Investment scenario and roadmap for achieving aviation Green Deal objectives by 2050*, Study Requested by the TRAN Committee (PE 699.651 – September 2022) https://www.europarl.europa.eu/RegData/etudes/STUD/2022/699651/IPOL_STU%282022%29699651_EN.pdf, p. 39.

[17] Royal NLR, SEO Amsterdam Economics. (2020). Destination 2050 - A route to net zero European aviation. Retrieved from https://www.destination2050.eu/wp-content/uploads/2021/03/Destination2050_Report.pdf; Electric taxiing. (2016, August 16). Retrieved June 2, 2021, from https://www.safran-landing-systems.com/systems-equipment/electric-taxiing-0.

[18] Air Transport Analytics, Understanding the potential and costs for reducing UK aviation emissions – Report to the Committee on Climate Change and the Department for Transport, November 2018, from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/ata-potential-and-costs-reducting-emissions.pdf

[19] EUROCONTROL, Flying the 'perfect green flight': How can we make every journey as environmentally friendly as possible?, by Aviation Intelligence Unit, Think Paper #10 - 20 April 2021, from: https://www.eurocontrol.int/sites/default/files/2021-04/eurocontrol-think-paper-10-perfect-green-flight.pdf

[20] T&E, Roadmap to climate neutral aviation in Europe, March 2022, from: https://www.transportenvironment.org/wp-content/uploads/2022/03/TE-aviation-decarbonisation-roadmap-FINAL.pdf

[21] Muthukrishnan M., Ahmed R. (2022). Green taxiing solution at Delhi Airport, ICAO Environmental Protection Report, CHAPTER 6 Climate Change Mitigation: Operations, pp. 156-159, from: https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art40.pdf

[22] Sustainable Taxiing at Schiphol Airport (Schiphol, 2020)

[23] AEON – Dashboard on sustainable taxiing techniques

[24] ICAO Doc 4444, Procedures for Air Navigation Services — Air Traffic Management – 16th edition 2016 - Order Number: 4444 - ISBN 978-92-9258-081-0

[25] ICAO Annex 14: Aerodromes, Volume I Aerodrome Design and Operations – 2016.

[26] IATA Ground Operations Manual (IGOM) 9th Edition 2020 English – Code IATA9409-09 A-SMGCS Eurocontrol Specifications EUROCONTROL-SPEC-171 version 2.0 issued 22 April 2020.

[27] Fezzazi, S., Tessier, D., Frings, C., (2022) *Airbus Single-Engine-Taxi, Sustainable Taxiing Taskforce - Workshop #3*.

[28] Jones, O.N., de Groot, J., (2022) *Single Engine Taxi Out/In (SETO/I): Fuel Savings and Standard Operating Procedures (SOPs)*, TUI Airline.

[29] Cousy, M., Peyruqueou, V., Pierre, C., Priou, C., Vo, D. B., Garcia, J., Mitici, M., van Oosterom, S., Sharpanskykh, A., von der Burg, M., Roling, P., Spiller, E., Gottofredi, S., & Lanzi, P. (2022). AEON: TOWARD A CONCEPT OF OPERATION AND TOOLS FOR SUPPORTING ENGINE-OFF NAVIGATION FOR GROUND OPERATIONS. Towards Sustainable Aviation Summit, 18-20 October 2022, Toulouse

[30] Bernatzky, T., Kemmerzell, M., Klingauf, U. and Schachtebeck, P.M. 2017. Development and evaluation of a speed guidance interface for trajectory-based dispatch towing. 2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC) (Sep. 2017), 1–8.

[31] SESAR Solution PJ.04-01 SPR-INTEROP/OSED for V2 - Part I edition 01.02.00 issued 18 January 2019.

[32] Taxibot company, “TaxiBot Operational Concept Manual for Amsterdam Schiphol Airport”.

[33] Pillirone, G. (2020), Greener aircraft taxiing, SESAR Webinar on Smart and sustainable solutions for greener ATM - Airport domain.

[34] Stettler, M., Koudis, G., Hu, S., Majumdar, A., & Ochieng, W. (2018). The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions. The Aeronautical Journal, 122(1258), 1967-1984. doi:10.1017/aer.2018.117.

[35] Prent and Bresser (2020), Greener aircraft taxiing, SESAR Webinar on Smart and sustainable solutions for greener ATM - Airport domain.

[36] Varadarajar, M, Lanzi, P, Cousy M. (2021), A keystone to sustainable green aviation!, International Airport Review.

[37] EUROCONTROL Performance Review Report 2019.

[38] Taxibot company, “TaxiBot Operational Concept Manual for Amsterdam Schiphol Airport.”

[39] ETSI EN 303 212 V1.1.1 Airport Collaborative Decision Making (A-CDM); Community Specification for application under the Single European Sky Interoperability Regulation EC 552/2004

[40] ED-141 System Requirements Document

[41] ED-145 Interface Definition Document

[42] ED-146 Test and Validation Document

[43] EUROCONTROL Specification for A-SMGCS Services https://www.eurocontrol.int/publication/eurocontrol-specification-smgcs-services

[44] ICAO Aerodrome Design Manual (section 1.2): https://skybrary.aero/sites/default/files/bookshelf/3090.pdf

[45] AEON D7.3 Final Project Results Report

[46] SESAR3 JU, European ATM Master Plan, 2022

Appendix A Additional Safety Requirements

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0002
Title	Use of provided handles for tugs
Requirement	Tug drivers shall use provided handles
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0003
Title	Safety shoes
Requirement	Tug drivers shall wear safety shoes
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0004
Title	Tug driver’s seat
Requirement	Tug driver’s seat shall be turned in driving direction
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0010
Title	Insulated tools
Requirement	Tug driver shall use insulated tools

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Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0011
Title	Insulated tools
Requirement	Tug drivers shall regularly examine electrical devices and report defects
Status	In progress
Rationale	Directly related to the identified safety hazards
Category	Safety

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