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AEON

ADVANCED ENGINE OFF NAVIGATION

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 892869 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document is the SPR-INTEROP/OSED for the AEON Solution "Advanced Engine-off Navigation" for V1 phase before any validation exercises have been performed on this subject. It provides the initial 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.

It is developed for V1 phase, as AEON is classified as applied exploratory project, and includes only Part I because it has been defined before any validation exercises have been performed.

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.

A consolidated and more complete version of the SPR-INTEROP/OSED will be released later on as D1.2, in order to take into account, the results of the validation exercises planned in the second year of the project.

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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, hybrid towing taxing solutions and autonomous taxiing solutions based on electric motors.

The present document provides the initial 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 because it has been defined before any validation exercises have been performed.

A consolidated and more complete version of the SPR-INTEROP/OSED will be released later on as D1.2, in order to take into account, the results of the validation exercises planned in the second year of the project.

This deliverable takes as input the research reported in deliverable D1.3 ‘State of the Art’, 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 taken into account 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. In particular, it is important to consider that this document is expected to be read in parallel with another deliverable being released together, D3.1 ‘Representative Use Cases’, that presents the use cases taken into account by the project.

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

Two key elements of the SESAR long-term vision concern the **full integration of airports** as nodes into the network, and the **environmental sustainability of air travel** to reach the EU's carbon neutral goal by 2050. On the one hand, the future European ATM system relies on enhanced airport operations, ensuring a seamless process through collaborative decision-making, in normal conditions, and through the further development of collaborative recovery procedures in adverse conditions. On the other hand, the growing environmental concerns in Europe and worldwide prompt the aviation industry to step up and define solutions able to increase the environmental sustainability.

In 2019, it is estimated that airports handled an average of 140 million aircraft ground movements [11]. The average fuel consumption during such ground operations is calculated to be about five per cent of the total quantity of fuel used during flight from apron to apron. This value of consumption is approximately five million litres of jet fuel per day, corresponding to about 12,750 tonnes per day of CO_2 emission [6].

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 greener taxiing solutions.

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 datapack for industrialisation and deployment. The SPR-INTEROP/OSED represents one of the key parts of the SESAR Solution datapack. 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 initial 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 because it has been defined before any validation exercises have been performed on the subject.

A consolidated and more complete version of the SPR-INTEROP/OSED will be released later on as D1.2, in order to take into account the results of the validation exercises planned in the second year of the project. The new release will also include Part II to V.

2.2 Scope

This document is the SPR-INTEROP/OSED for the AEON Solution "Advanced Engine-off Navigation" for V1 phase before any validation exercises have been performed on this subject. **It provides the initial**

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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 them 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 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 taken into account 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.

The CONOPS presented in this document, along with representative use cases presented in D3.1, will inform the design of the algorithms designed in WP2 and described in deliverables D2.1 “Models and algorithms for autonomous and non-autonomous taxiing operations” and D2.2 “Model for optimal allocation of towing vehicles to flights both at the strategic and tactical phase of the operations. It will also feed the design of the supervision HMI prototype developed in WP3 and reported in D3.2 “Supervision HMI and patterns of interaction”. It will be also validated against the goals outlined in D5.1 “Assessment Plan” and the detailed test scenarios presented in D3.1 “Use Cases” [2], using the validation platform described in D4.1 “Description of the first validation platform”.

Together with the validation results described in D5.2 ‘HP Assessment Report”, D5.3 “Safety Assessment Report” and D5.4 “Cost Assessment” the present document will then feed the deliverable D1.2 ‘Concept of Operations Final version”.

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 Background

The contents of this SPR-INTEROP/OSED derive from a series of activities carried out during the first year of the AEON project. As represented in the following figure, they concern in particular:

- the analysis of the state of the art reported in D1.3 [1]
- the results of an online survey about green taxiing techniques organised by the consortium
- a number of field visits and one-to-one meetings and interviews with relevant stakeholders organised by the consortium
- the analysis of current regulations and procedures
- the feedback collected from the Advisory Board (AB) during the first Advisory Board meeting held in September 2021, that was explicitly targeted and dedicated to this purpose
- initial design proposals at Human-Machine Interaction (HMI) level and for the algorithms produced by the consortium

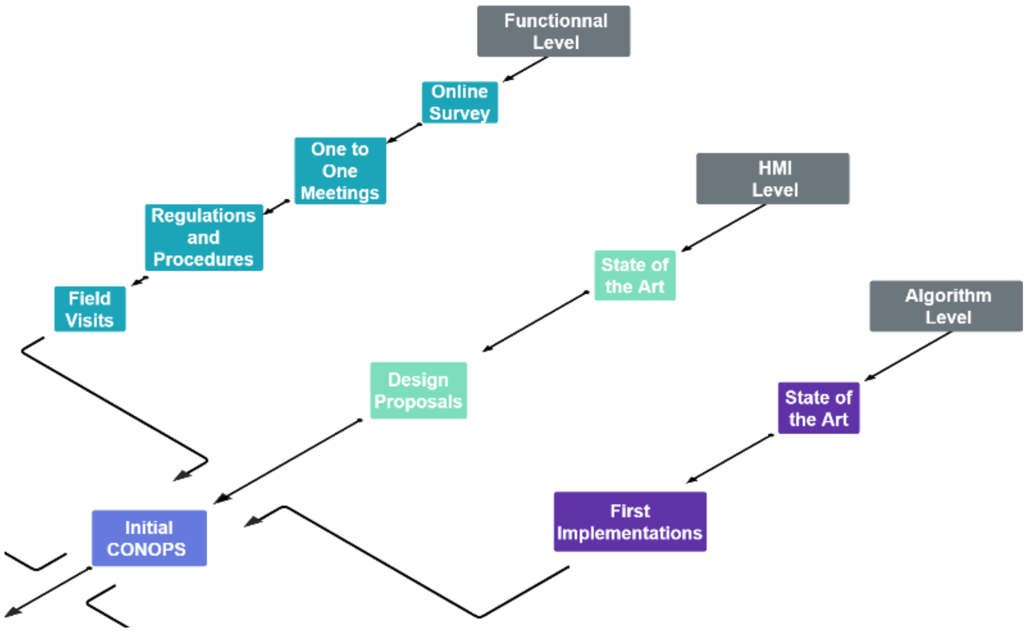

Figure 1: Inputs to the AEON initial CONOPS

2.6 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 an initial 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 in order to provide a more complete view of the operational concept.

2.7 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
DTVETS	Dispatch Towing Vehicle Electric Taxi System

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
LGETS	Landing Gear Electric Taxi System
LTO	Landing and Take Off (cycle)
LVC	Low-Visibility Condition
MLGETS	Main Landing Gear Electric Taxiing System
NB	Narrow Body

NLGETS	Nose Landing Gear Electric Taxiing System
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 (Agency of the European Commission)-
SPR	Safety and Performance Requirements
SWIM	System Wide Information Model
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

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3 Operational Service and Environment Definition

3.1 The AEON Solution: a summary

The AEON Solution moves from the consideration that three classes of engine-off techniques are currently under design and/or development with the purpose of reducing the environmental impact of ground operations. They focus respectively on single-engine taxiing solutions, hybrid towing taxing solutions and autonomous taxiing solutions based on electric motors. A brief description of each of them is provided hereafter.

Single-engine taxiing solutions

Single-engine taxiing (SET) solutions involve the use of only half the number of engines installed to generate the energy needed for taxiing. The idea derives from the consideration that aircraft taxiing operations are a significant source of energy consumption and emissions at airports and a reduced number of engines can provide enough power to move the aircraft on the ground. On average this kind of solution is expected to reduce taxi fuel consumptions by 20%, with potential fuel saving depending on the a/c type that can range from a minimum of 2 Kg/min to a maximum of 13 kg/min [3]. With reference to large airports, a recent study using the London Heathrow airport as a case study, has shown that reducing the time before SET is initiated to the 25th percentile of observed values, reduces the fuel consumption, NOx, CO_2 and HC emissions by 6.7%, 8.7%, 14.2% and 11.5%, respectively, relative to observed levels [4].

Although several airlines have already adopted this solution, its concrete applicability depends on specific operational and contextual factors and may imply specific challenges. **As a general consideration, using half of the engines may affect the aircraft performances, in particular its manoeuvrability and balance. Consequently, not all the taxiways are suitable for single-engine operations, neither all weather conditions. Similarly, the solution is not equally applicable to both taxiing procedures. In general, taxi-in is considered easier to manage in single-engine operations than taxi-out**, due to the less workload associated to monitoring the engine cooldown (with respect to warmup) and the higher predictability of taxiing duration. Thus, some of the airlines who adopted it have authorized the use of single-engine operations only during the taxi-in procedure.

According to a recent estimate, currently single-engine taxi is used in about 50% of taxi-in procedures in which the operational and contextual conditions would allow to use it and in less than 10% of taxi-out procedures [3]. An accurate and reliable indication of the time until take-off could favour a larger use of single-engine operations during the taxi-out operations as it would give the pilots confidence in the decision making and allow to start the second engine not too late and/or not too early.

Non-autonomous taxiing solutions

Non-autonomous taxiing solutions are based on the use of hybrid towing vehicles, such as TaxiBots [7], which, unlike the normal pushback trucks, can tow full aircrafts to near the start of the runway, without the aircraft having to start its engines. The use of this kind of non-autonomous solutions is expected to reduce fuel consumption during taxiing by 50%- 85%. The generic name of Dispatch Towing Vehicle Electric Taxiing System (DTVETS) has been chosen for this concept in the framework of AEON.

A recent live trial study conducted at Amsterdam Schiphol airport (NL) on 170 missions, revealed a potential annual savings of 50-70% fuel (equal to € 25 million fuel costs), 124.700 ton CO2 / 647.800kg NOx emissions and noise and (ultra) fine particles reduction [5]. Nevertheless, the same study also highlighted that **to safely profit by the advantages of this solutions changes shall be introduced on three fundamental dimensions: at technical level, to decrease the decoupling time, in the airport infrastructure, to introduce out-of-the-flow uncoupling positions, and last but not least in the work on the ground controller.**

Moreover in a systemic perspective it is important to consider that the adoption of non-autonomous engine-off taxiing techniques would imply an increase in traffic size, due to towing vehicles circulating on the platform. As a consequence the impact of such traffic increase on workload and situational awareness of ground operators shall be carefully considered.

Autonomous taxiing solutions

Autonomous taxiing solutions rely on electric motors, like E-Taxi system or WheelTug, that are embedded in landing gear or nose wheel gear to allow airplanes to push back and taxi without their jet engines running, thus saving fuel, curbing emissions and ending last-minute delays while waiting for airport tugs. The use of this kind of autonomous solutions is expected to imply a reduction in fuel costs of around 4% of the overall consumption, considering a 50% taxiing fuel saving and up to 85% of ground operations costs-savings related to other benefits in pushback costs, brake wear etc. The generic names of Nose Landing Gear Electric Taxiing System (NLGETS) and Main Landing Gear Electric Taxiing System (MLGETS) have been chosen for these concepts in the framework of AEON.

Noteworthy, **the different solutions taken into account are not at the same level of maturity.** Single-engine taxiing solutions are already in use. Non-autonomous taxiing solutions such as TaxiBots have been in live trials in several airports. Nose Landing Gear Electric Taxiing System, specifically WheelTug, is in the process for certification on B737 by Federal Aviation Administration (FAA). The E-Taxi system can be considered still at the Research and Development (R&D) maturity phase.

Moreover, **the various solutions have unique characteristic of operation, strengths and potential challenges and drawbacks that make them not applicable in all the operational conditions, thus affecting the way they can be integrate in the airport environment and thus contribute to the overall objective of reducing fuel consumption and emissions.**

The AEON solution

The AEON solution proposes a novel operational concept for more sustainable and efficient operations on the ground, which relies on the above-mentioned techniques [6].

The operational concept moves from the consideration that in the future the different engine off techniques (single-engine, autonomous taxiing solutions and non-autonomous taxiing solutions) presented above may become robust technologies. In this future scenario there will be the need for them to coexist in the airport environment and to be used in a coordinated way thus overcoming the specific limitations that each of them has in the operations and pursuing the overarching purpose of making ground operations more sustainable and eco-friendly. 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 them 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.

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.

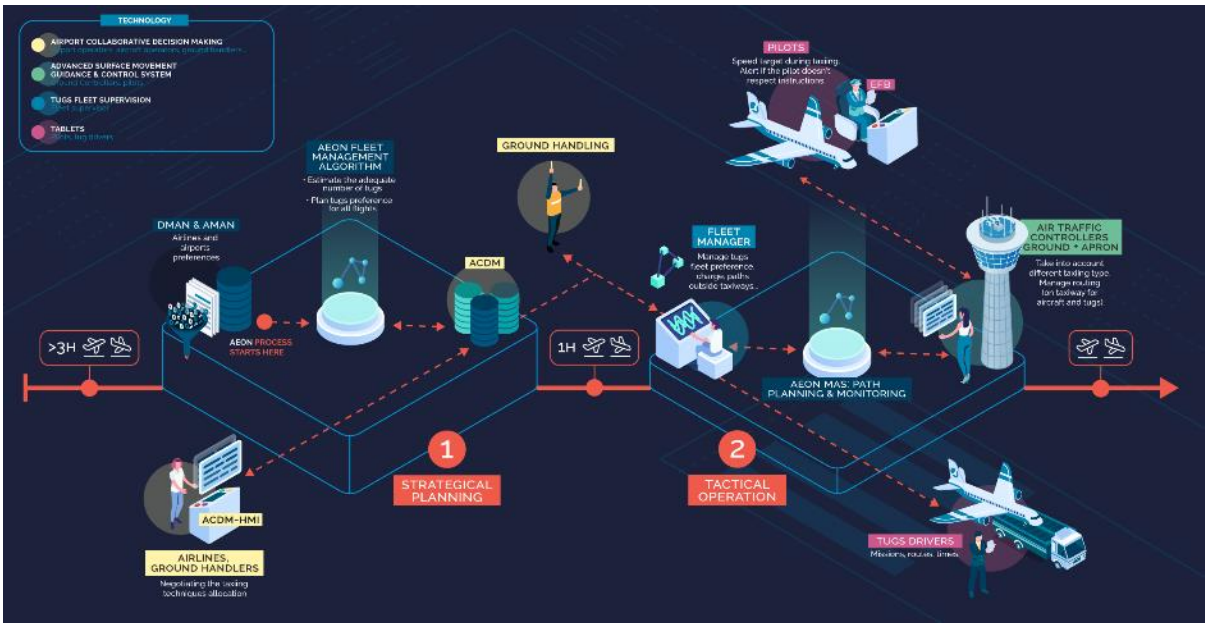

Figure 2: AEON Concept Image

At **strategical phase**, a support tool will help estimate the adequate number of DTVETS 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 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 in order to facilitate engines start-up procedure, and
- help reassign DTVETS when operational events modify the initial plan.

In addition, the AEON solution considers that the aircraft using electrical engines for taxiing (or towed by electric 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. However, this new type of ATC clearances would create additional workload and radio frequency usage, in consequence, AEON will explore the possibility to give speed cues to the pilot through datalink, to be displayed on the electronic flight bag.**

The following figure provides a representation of the AEON eco-system from strategical planning to tactical operations.

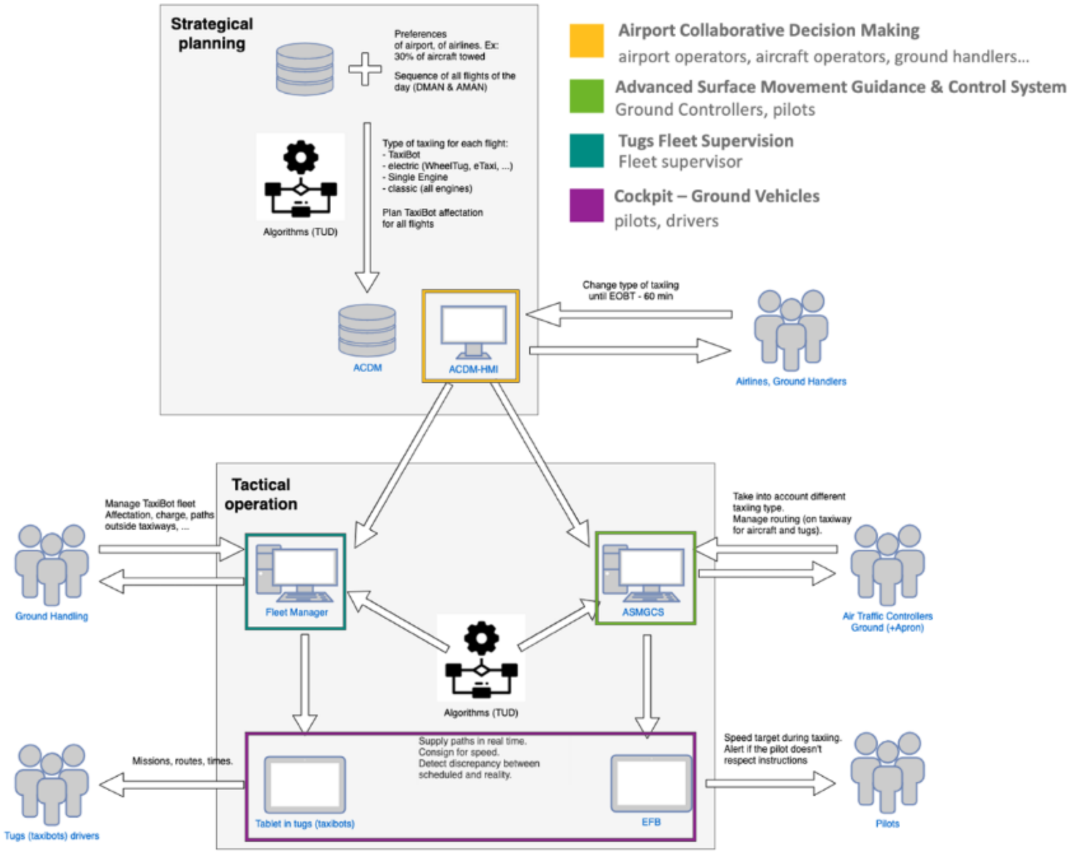

Figure 3: Overview of AEON eco-system from Strategical planning to tactical operations

Operational improvements and enablers

The table below lists the Operational improvements (OIs) and/or Enablers on which the AEON solution will have an impact. They concern three main aspects, namely:

- Collaboration on pre departure 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.

SESAR Solution ID	SESAR Solution Title	OI Steps ID	OI Steps Title	Enabler ID	Enabler Title	OI Step/Enabler Coverage
		AUO-0805	Incorporation of Autonomous Engine-off Taxiing into			Full coverage

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			surface operations			
		AUO-0806	Incorporation of Non-Autonomous Engine-off Taxiing into surface operations			Full coverage
		AUO-0807_Extended	incorporation of single engine taxiing into surface operations			Full coverage
#21	Airport Operations Plan and (AOP) – Network Operations Plan (NOP) Seamless Integration	AO-0801-A	Collaborative Airport Planning Interface	AIRPORT-31	Airport CDM (levels 1, 2 & 3)	Partially covered: Airport CDM will be impacted on variable taxi time calculation elements and collaborative pre-departure sequence
#21	Airport Operations Plan and AOP-NOP Seamless Integration	AO-0801-A	Collaborative Airport Planning Interface	HUM-009	New role of APOC representative from Airport Operator	A new role of tugs fleet supervision is considered
#21	Airport Operations Plan and AOP-NOP Seamless Integration	AO-0801-A	Collaborative Airport Planning Interface	AERODROME-ATC-57	Advanced Airport Tower CWP to support new functionalities	Partially covered: New functionalities to show a/c taxi technique and control tugs
#53	Pre-Departure Sequencing supported by Route Planning	TS-0202	Pre-Departure Sequencing supported by Route Planning	AERODROME-ATC-18	Interfacing between DMAN and Routing module	Partially covered: AEON takes DMAN sequence as input and uses its routing module to support taxiing technique allocation and path planning
#22	Automated Assistance to Controller for Surface Movement Planning and Routing	AO-0205	Automated Assistance to Controller for Surface Movement Planning and Routing	AERODROME-ATC-50	Advanced Airport Tower Controller Working Position (A-CWP)	Partially covered: Controller will be provided with new routing system and support to decide tugs detaching points.
#22	Automated Assistance to Controller for Surface Movement Planning and Routing	AO-0205	Automated Assistance to Controller for Surface Movement Planning and Routing	AERODROME-ATC-12	Provision of automatically generated taxi routes for aircraft and vehicles	Partially covered: Controller will be provided with new routing system and tugs detaching points support.

#22	Automated Assistance to Controller for Surface Movement Planning and Routing	AO-0205	Automated Assistance to Controller for Surface Movement Planning and Routing	AERODROME-ATC-13	Surface movement information processing system enhanced with storage and dissemination of surface routes	Partially covered: AEON tool will endspeed cues to vehicles and display them to the pilots / drivers
PJ.03a-01	Enhanced Guidance Assistance to Aircraft and Vehicles on the Airport Surface Combined with Routing	AO-0206	Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	AIRPORT-44	On-board vehicle display for taxi information and clearances, using common airport map database	Partially covered: AEON will look at sending speed cues to vehicles and display them to the drivers and pilots
PJ.03a-01	Enhanced Guidance Assistance to Aircraft and Vehicles on the Airport Surface Combined with Routing	AUO-0308-B	Datalink Services used for Provision of Ground-related Clearances and Information for trajectory-based operations	AERODROME-ATC-02b	Surface movement management tools updated to provide the data-link information to the pilot for Trajectory Based Operations	Partially covered: AEON will look at sending speed cues to vehicles and display them to the pilots
PJ.03a-01	Enhanced Guidance Assistance to Aircraft and Vehicles on the Airport Surface Combined with Routing	AO-0215	Airport ATC provision of ground-related clearances and information to vehicle drivers via datalink	AERODROME-ATC-14	Surface movement management tools updated to provide ground clearances and information to the vehicle driver	Partially covered: AEON will look at sending speed cues to vehicles and display them to the drivers
#23	D-TAXI service for Controller-pilot data link communications (CPDLC) application	AUO-0308-A	Datalink Services used for Provision of Ground-related Clearances and Information (D-TAXI)	AERODROME-ATC-02a	Surface movement management tools updated to provide the D-TAXI information to the pilot	Partially covered: AEON will look at sending speed cues to vehicles and display them to the pilots
#23	D-TAXI service for CPDLC application	AUO-0308-A	Datalink Services used for Provision of Ground-related	A/C-42a	On-board graphical display of taxi clearance (up linked or via voice) using	Partially covered: AEON will look at sending speed cues to vehicles and display

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			Clearances and Information (D-TAXI)		common air/ground airport database	them to the drivers / pilots
		AUO-0603-B	Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing for trajectory based operations			Partially covered: AEON will look at sending speed cues to vehicles and display them to the drivers / pilots
		AO-0813_Enhanced	Collaborative Airport Performance Management			

Table 2: SESAR Solution AEON Scope and related OI steps/enablers

<u>Assumptions</u>

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 electrical engines for taxiing (or towed by electric tugs) are more easily controlled on speed, i.e. they can take speed target and follow them. AEON will provide speed target to avoid aircraft arriving simultaneously on the same intersection, hence smoothing traffic control. However, this new type of ATC clearances may create additional workload and radio frequency usage. As a consequence, AEON will explore the possibility to give speed cues to the pilot through datalink, to be displayed with the aircraft equipment such as EFB or moving maps.

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

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

3.2 Detailed Operational Environment

The operational environment described in this OSED is associated with all kinds of ground operations in the airport environments, from high to low complexity. However, more emphasis will be put on airports being characterised by high complexity 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.

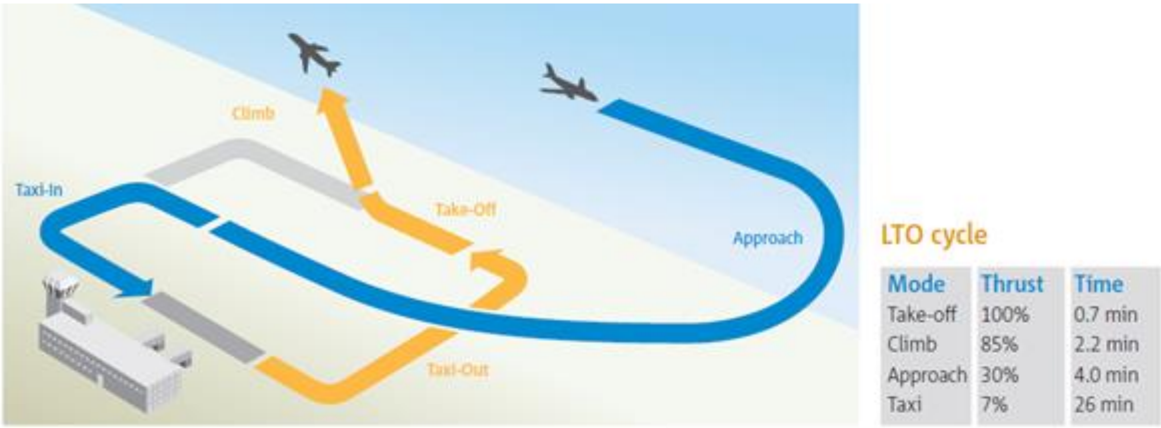

Figure 4: Landing and take-off cycle

3.2.1 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.

These techniques can be operated using external means or through on-board aircraft systems. They can also be used independently or in combination, by adopting an engine-off technique with an engine-on method such as for example: single engine taxi with e-taxi technique, which we refer here as 'Hybrid' mode, in order to achieve 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 characteristic 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. The current operations do not offer complete engine off techniques that are integrated into an HMI interface platform.

3.2.2 Roles and Responsibilities

The AEON solution is expected to affect the roles and responsibilities of most of the actors who are 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 sections 3.3.2. Please notice that at this stage of the concept development the Network Management 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.

	**Aircraft Operator (AO) / Airlines** A person, organisation or enterprise engaged in, or offering to engage in aircraft operation.
	**Airport Operator (APTO)** A person, organisation or enterprise engaged in or offering to engage in an airport operation.
	**ANSP / ATS: Air Navigation Service Providing and Traffic Services** The service provided by Air Traffic Controllers (ATCO) working at airports for the arrival and departure flight phases and in Air Traffic Control Centers (ACC) for the en-route flight phase. En-route ATCOs, Ground Controller, AC – Apron Controller and OP – Outbound Planner.
	**Dispatch Towing Vehicle Electric Taxi System (DTVETS) Operator** DTVETS operation involves aircraft pushback from an airport gate by external power, and power and drive back post uncoupling of the tug from the aircraft. This is usually provided by DTVETS tugs that are driven by trained drivers.
	**Flight Crew (FC)** The personnel who are responsible for the operation of an aircraft during flight. The two main actors are: PIC (Pilot in Command) and FO (First officer).
	**Ground Handler (GH)** Company responsible for handling of aircraft during turn-round at the airport.
	**Pushback or Tug Operator** Pushback is an airport procedure that results in an aircraft being pushed backwards away from an airport gate by external power, which is usually provided by pushback tractors or aviation tugs that are driven by trained drivers.

3.2.3 Impacts on already existing systems and tools

The AEON solution is expected to impact two systems already existing and used in the airport environment, namely:

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

In addition, it is worth considering that the AEON solution, introducing the usage of DTVETS will also imply additional vehicles to be managed, while a new role of tug fleet manager, supported by a tool, will be introduced.

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3.2.3.1 Airport Collaborative Decision Making

In EUROCONTROL A-CDM Implementation manual Version 5.0 (31 March 2017), §3.2.3 provides the following list of the high-level information provided by the main actors of the system.

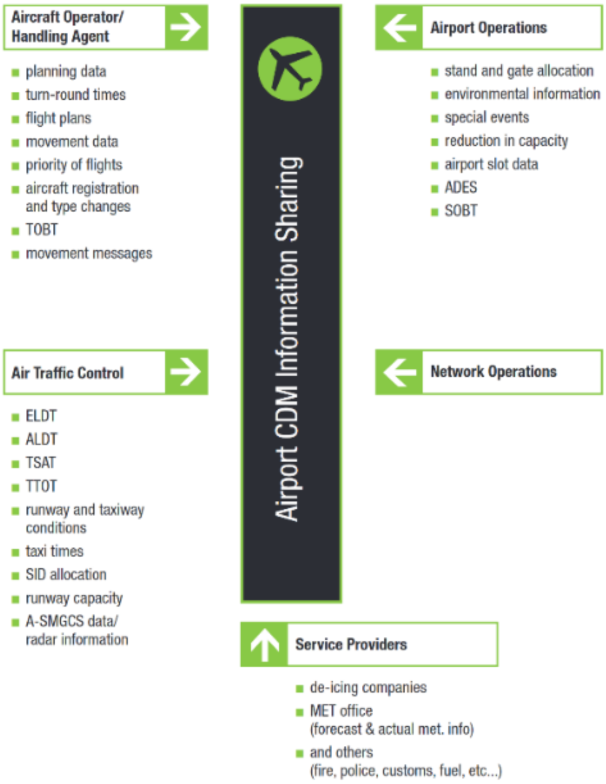


Figure 5: A-CDM data sources

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 DTVETS 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.

In the milestone approach for turnaround process (represented below), the AEON solution will not add an additional milestone. Instead, it will use Milestone #10 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 when Milestone #10 is issued, 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.

Number	Milestones	Time Reference	Mandatory / Optional for Airport CDM Implementation
1	ATC Flight Plan activation	3 hours before EOBT	Highly Recommended
2	EOBT – 2 hr	2 hours before EOBT	Highly Recommended
3	Take off from outstation	ATOT from outstation	Highly Recommended
4	Local radar update	Varies according to airport	Highly Recommended
5	Final approach	Varies according to airport	Highly Recommended
6	Landing	ALDT	Highly Recommended
7	In-block	AIBT	Highly Recommended
8	Ground handling starts	ACGT	Recommended
9	TOBT update prior to TSAT	Varies according to airport	Recommended
10	TSAT issue	TOBT -30 mins to -40 mins	Highly Recommended
11	Boarding starts	Varies according to airport	Recommended
12	Aircraft ready	ARDT	Recommended
13	Start up request	ASRT	Recommended
14	Start up approved	ASAT	Recommended
15	Off-block	AOBT	Highly Recommended
16	Take off	ATOT	Highly Recommended

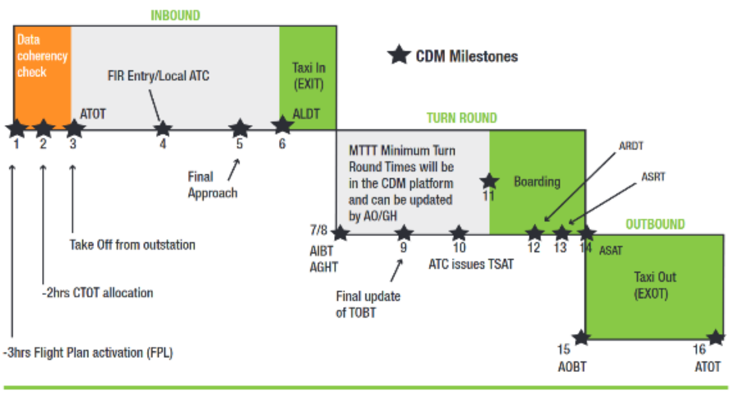


Figure 6: A-CDM milestones

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 timings 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.

3.2.3.2 ADVANCED SURFACE MOVEMENT GUIDANCE AND CONTROL SYSTEM

The EUROCONTROL Specification for Advanced Surface Movement Guidance and Control System A-SMGCS (EUROCONTROL-SPEC-171 ed. 2.0, 22 April 2020), defines the actors involved by the system (see figure below) and the four services it provides: Surveillance Service, Airport Safety Support Service, Routing Service, Guidance Service.

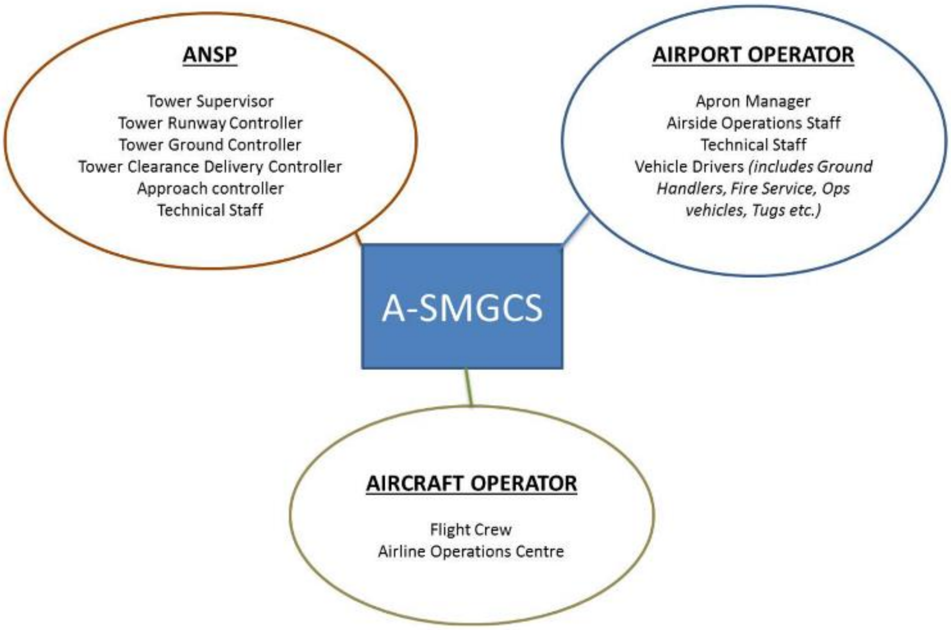


Figure 7: A-SMGCS business organisation

The Surveillance service is not impacted functionally by the AEON solution, the only potential difference with respect to current operations being aircraft towed by tugs, but in that case, it shall behave exactly as towed aircraft. Empty tugs driving alone will have their own squawk and appear on the radar image in the same manner as a service vehicle does. However, the taxiing technique planned or in use for a given aircraft shall appear in its labelling or representation.

In the same manner, the Airport Safety service shall still operate as usual.

The AEON solution will follow the Routing service specification as currently stated. However, in order to reduce the Controller workload, it will explore the possibility to use technologies under development within SESAR such as Datalink for routing clearances (see table 2).

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.

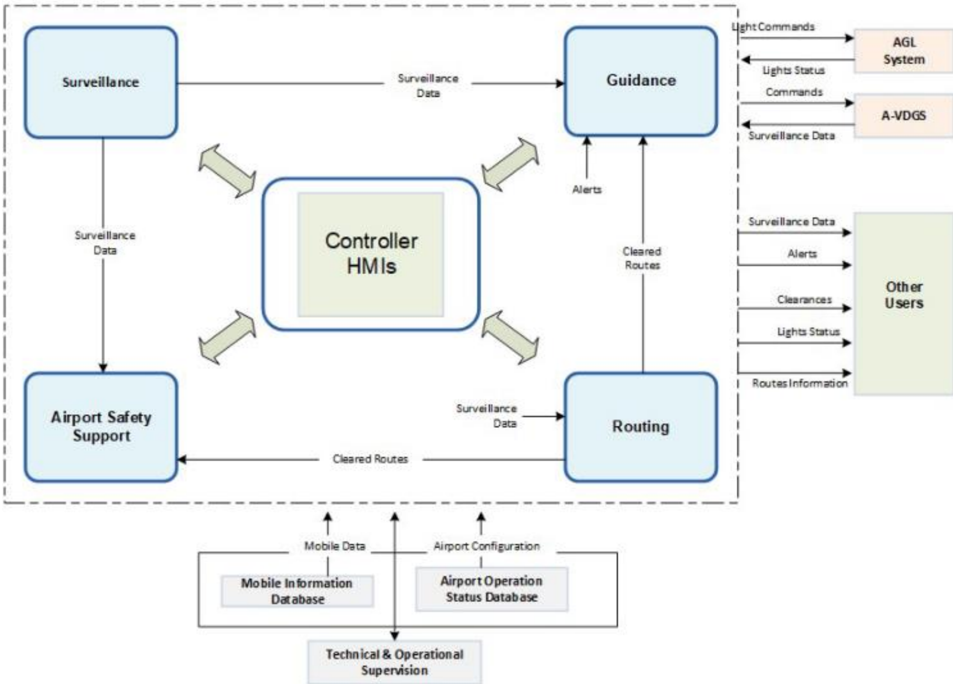


Figure 8: A-SMGCS Architecture

3.2.4 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 industry 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 standards and regulations that are followed in the SESAR solution, few notable ones are used to define the framework of the CONOPS, namely ICAO 4444 [8], ICAO Annex 14 [9] and IATA IGOM (9th Edition) [12].

3.3 Current operating method

Today's operating methods on ground involve keeping main engines-on or use single engine technique to taxi aircraft from gate to runway or vice versa as shown in Figure 9.

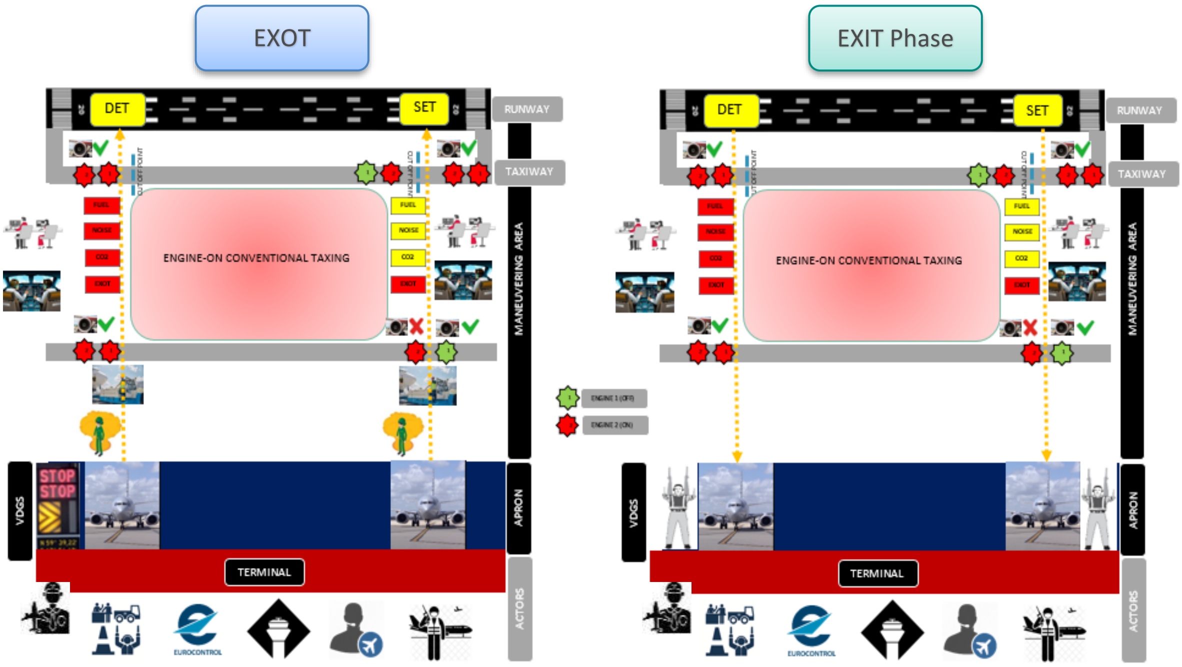
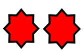
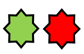


Figure 9: Current operating method – DET and SET

The Dual Engine Taxi (DET) are normally adopted during both Taxi-Out (EXOT) and Taxi-In (EXIT) phases of aircraft ground operations. Single Engine Taxi (SET) method are usually used by airlines during the EXIT phase more than the EXOT phase, to save fuel during longer taxiing times at the airports. It can also be seen that these methods add procedures/personnel on ground that eventually increase the turnaround time for the AO. Figure 9 also shows that engines are kept on right from the aircraft off-block time till the on-block time, even though there are stop and go situations that arise, like de-icing of an aircraft or airside delays causing aircrafts to hold for longer duration.

The  indicates both engines are ON while  indicates one engine is OFF and the other one is ON. The other parameters that are compared for the conventional technique with new AEON solution(s) are fuel saving, noise, CO_2 emission and EXOT or EXIT times. The EXIT and EXOT times are also dependent on situational awareness at the airport. Keeping all other factors constant these times vary with respect to engine start-up, pushback or wheel back procedures when compared with the new SESAR solution(s). Figure 9 also illustrates the actors and stakeholders who are involved at various stages of operation, from pushback on apron, taxiing in the manoeuvring area to take-off on the runway.

3.3.1 The 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.

3.3.1.1 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.

Figure 10 illustrates the step-by-step concept of operation of a typical narrow body aircraft that uses both the engines-on while departing and arriving.

Earlier, almost all aircraft types required the ground locking pin to be installed in the nose landing gear during any pushback; however, this is no longer always the case. If a ground-locking pin is installed for the pushback, it will need to be removed after the completion of the ground vehicle manoeuvre, which in turn adds more ground time to the operation.

The ‘traditional’ method of allowing the ground vehicle to move an aircraft is to attach at the coupling point to the aircraft nose landing gear by means of a towbar (TT). The same towbar attachment and ground vehicle may also be used for aircraft towing in the forward direction as illustrated in Figure 10. An alternative method, which is more common for pushback, is the use of a specialized vehicle called a ‘towbarless tug’. This tug positions two low level ‘arms’ either side of the aircraft nose landing gear and these are used to engage with the aircraft gear leg and raise it slightly off the ground. These specialized vehicles can also be used to tow aircraft forward. Other methods using power push unit methods are also into commercial operation.

Figure 10 indicates the responsibilities of the ground crew team to carry out the pushback that includes, ensuring that no part of the aircraft structure will impact any fixed object or other aircraft and may include giving clearance to start one or more engines just before, during or immediately after a pushback. The number of people assigned to a ground crew team for a pushback may vary according to aircraft size. In most cases it involves the operators: one to drive the pushback vehicle, one to walk in the vicinity of one of the aircraft wingtips and look beyond the aircraft tail, and one in charge of the manoeuvre and in communication with the person with aircraft responsibility in the flight deck.

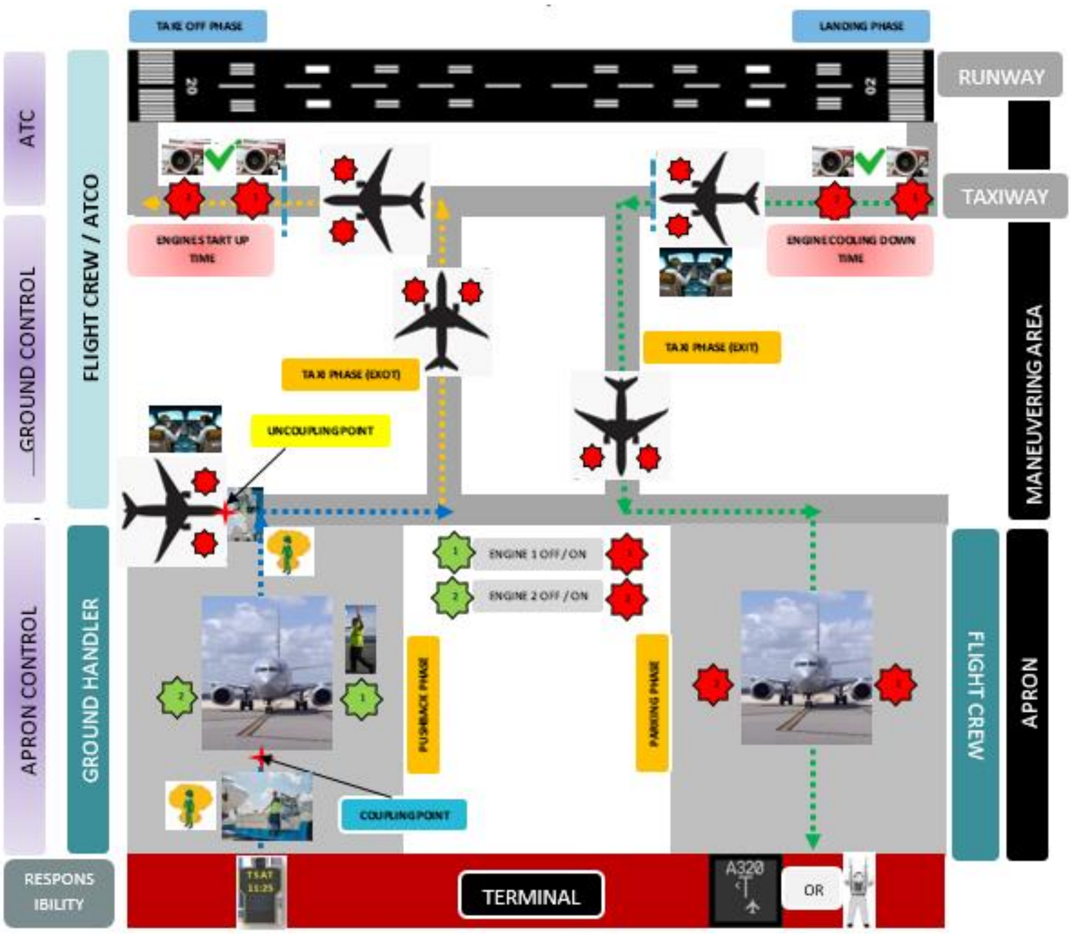


Figure 10: CONOPS for Dual Engine Taxi

A typical "pushback/engine start-up departure procedure" is represented in Figure 11, along with the communication between Ground Staff, Flight Crew, Ground Controller and ATC. For every Call (C1, C2 etc.) there is a corresponding Response (R1, R2 etc.) and/or Action (A2, A3 etc.).

Communication between the ground supervisor usually occurs by means of a plug in to an aircraft ground intercom circuit (Radiotelephony - RTF); if so, this is facilitated by a ground crew microphone which acquires the voice of the user whilst excluding background noise, especially when the aircraft engines are running. Figure 11 illustrates the communication exchange that takes place between the Ground Staff (GS) and the Flight Crew during the pushback procedure.

When the Flight Crew requests for pushback (C1), the ATCO responds via message (R1), while in response to the Flight Crew's (C2) message the Ground Staff responds accordingly through (R2) message and the Flight Crew acts upon by releasing the brakes through A2 message.

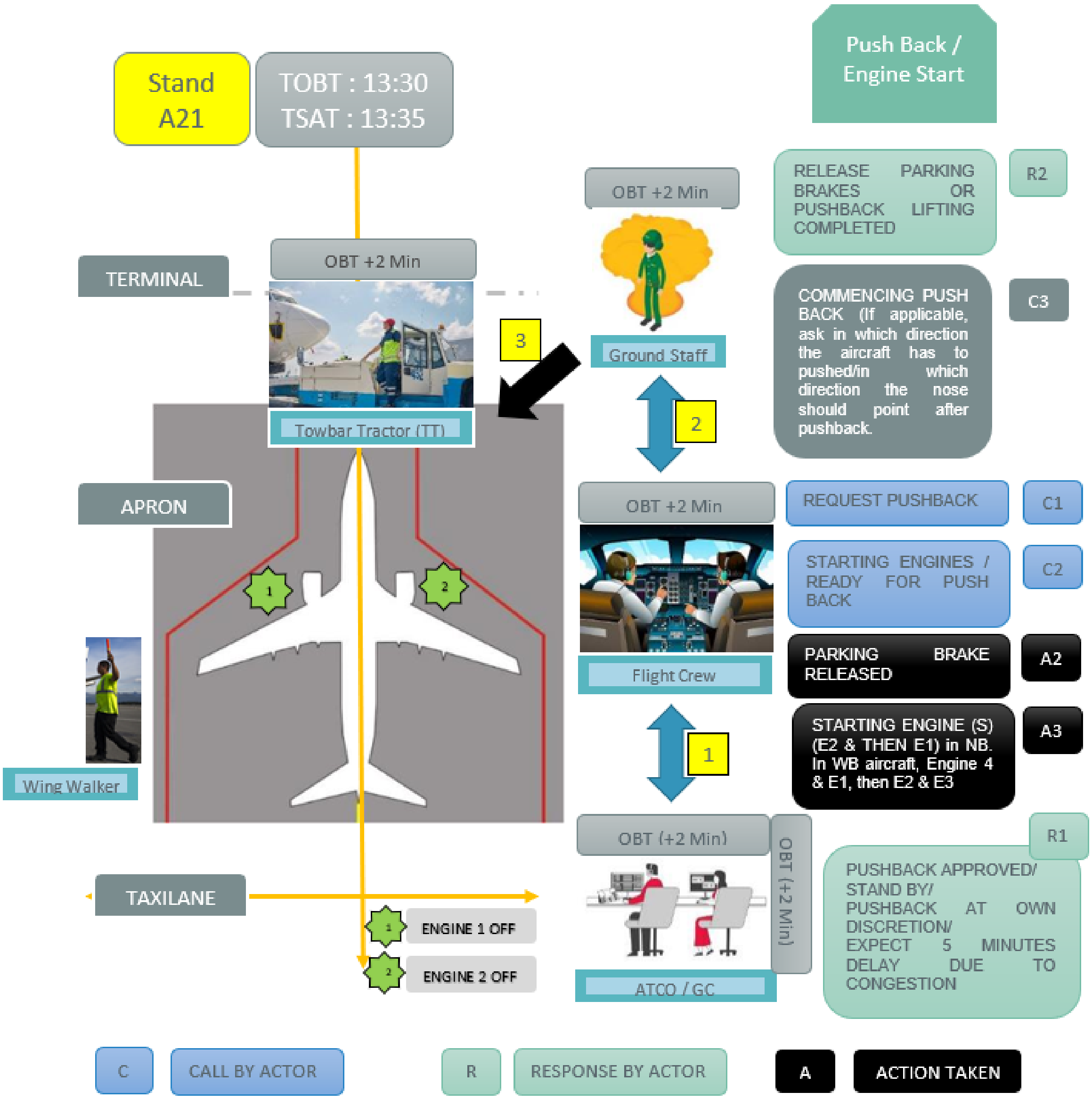


Figure 11: Communication exchange during Pushback

It is important that the procedure takes into account of the roles of each ground crewmember, and that the person in charge of ground crew communications on the flight deck is aware of the number of ground crew being used and of the physical location of the supervisor.

Effective communication between the person in charge in the flight deck and the person in charge of the ground crew, and between the members of the ground crew team is critical. If the aircraft is pushed back prior to intended flight and the person in charge of the flight deck is therefore an aircraft commander or PIC, the procedures of the aircraft operator may require that the designated pilot flying, who may be the co-pilot, should oversee the pushback and in this case all communications with the ground crew will be undertaken by that person rather than necessarily by the aircraft commander. If it is considered that communication by hand signals rather than intercom is acceptable then it is essential that the applicable procedures be comprehensive and thoroughly understood by both parties and that they cover all possible abnormal and emergency circumstances.

In Figure 11, the Ground Staff commences pushback (C3) in coordination with the Flight Crew, while the PIC decides to start the engine(s) during this process (A3).

The case of engines-running, pull forward as a supplementary action prior to ground vehicle disconnection after a pushback should be considered as part of the pushback procedure and trained accordingly since it bears little practical resemblance to the towing for longer distances of empty out-of-service with engines stopped.

Engine start-up may be routinely accomplished immediately before or during pushback as shown in communication between the Ground Staff and the Flight Crew. If it is carried out when the aircraft is moving, it is essential that the ground crew supervisor does not allow the checks and communication required in connection with engine starting to interfere with their primary responsibility to control the pushback and remain in full communication with those on the flight deck using the means available.

Many aircraft operators require that when push back is accomplished without headset communications, engine starts do not take place whilst the aircraft is being pushed, preferring instead to require that engine starting takes place before or after completion of the pushback. Observations of abnormal circumstances in connection with engine starts or any other matter affecting, or potentially affecting, the safety of the aircraft during a pushback are of great importance to those on the flight deck thus it is essential that any descriptions of external observations during engine starts is reported immediately. Occasionally, a pushback may need to be followed by an engines-running pull forward to a position where local procedures allow aircraft to move forward under their own power, but usually, ground vehicle disconnection occurs at the uncoupling point after the completion of a pushback. The pushback procedure then becomes complete after the Ground Staff gives an “all clear” signal to the PIC and the same is acknowledge by the PIC.

3.3.1.2 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 P (Gate or Parking stand) to D (Runway take-off point) as show below in **Erreur ! Source du renvoi introuvable.**.

After being cleared by the ground crew and with the warmed-up engines, the PIC is in a position 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 control and responsibility to operate the aircraft based on the local safety and environmental conditions. **The choice of speed to drive through taxiways would depend largely on the human factor, 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).

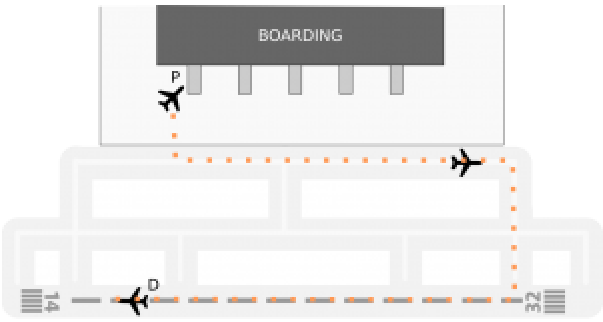


Figure 12: EXOT time calculation methodology

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 shown in Figure 13, and represented through a series of “C-Calls”, “R-responses” and “A-actions” taken by various accountable stakeholders.

When the parking brakes are set by the Flight Crew (R1), the Ground Staff instructs tug driver to disconnect the towbar (A1) and also confirms with Flight Crew for headset disconnection (C2/R2). As a follow up action, the Ground Staff removes the bypass pin (A1.1), moves to clear safety area and shows the bypass pin to give PIC the “all clear” (A3) signal to begin the taxi process.

Once taxied to the designated hold point closer to the runway, the Flight Crew readies the aircraft for take-off after taking into consideration the entire pre-departure checklist. On FC’s confirmation for aircraft readiness to take-off, necessary communications are exchanged between FC & ATCO, who in turn provide line-up and take-off clearances to the FC. This way a smooth transition for take-off is achieved.

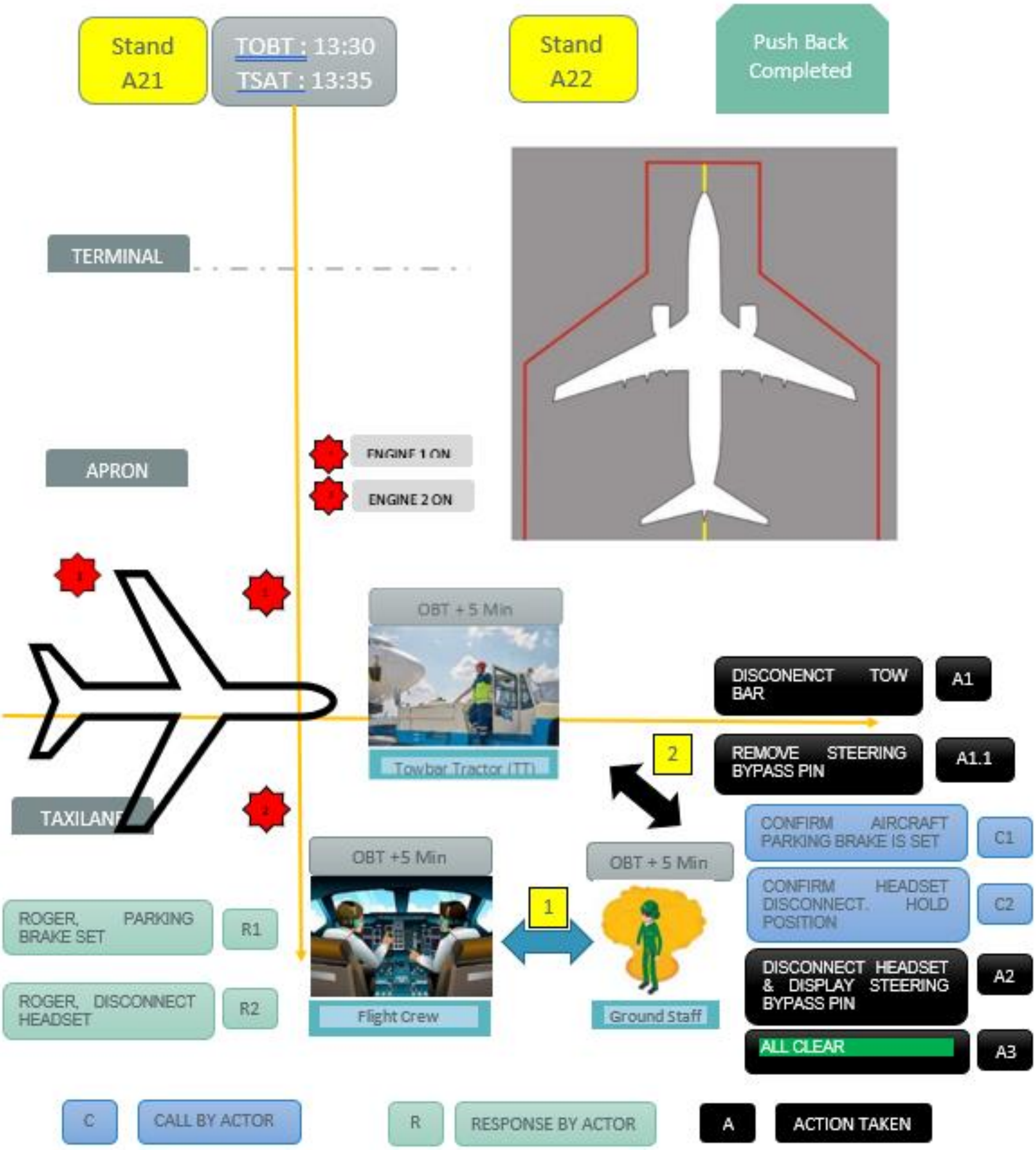


Figure 13: Communication exchange during Pushback completion process

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3.3.1.3 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 Point A (runway touch down) to P (Parking stand or Gate) as shown in Figure 14.

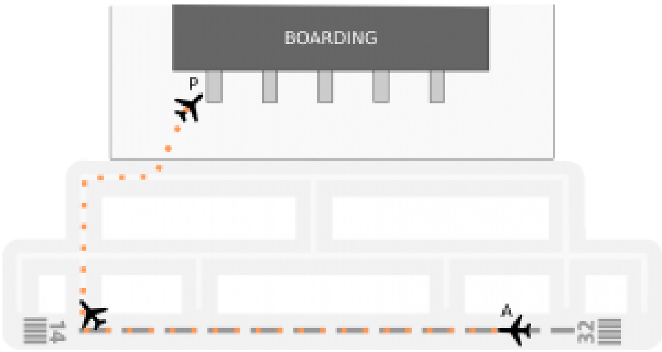

Figure 14: EXIT time calculation methodology

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**.

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.

It is interesting to notice that SET may increase the airside safety risk profile of an airport from a point of view of jet blast. Both airports and airlines have to find the balance between reducing carbon footprint and optimised airside capacity in order to make SET a more sustainable operational method. Figure 15 and Figure 16 illustrates the LTO cycle using both dual engine and single engine taxi. It is seen that, out of the 14min of taxi-out time only 3 min are used (engine warm up) for operating the second engine and during taxi-in phase, 50% of the time is used (engine cool down) for operating single engine.

The Flight Crew maximises the speed while taxiing (both during EXIT and EXOT phase) in order to reduce the quantum of round-trip time on ground. While on ground, prior to the arrival of the aircraft, several pre-arrival checks are carried out by the Ground Staff on apron, so as to ensure a safe and seamless in-block is achieved. The aircraft is guided into the apron stands using Visual Docking Guidance System (VDGS) or hand signals by trained marshallers. While taxing into the apron stand the PIC may operate the aircraft using single or both engines. After stopping at the designated nose wheel position with chocks on, brake released and upon engines being switched off and set into the cooling mode and once confirmed by the PIC, the Ground Staff begins the ground handling operation.

In order to best achieve an optimised round-trip time (RTT) or turnaround, the Airline Operator/Flight Crew and the Ground Staff take into account 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).

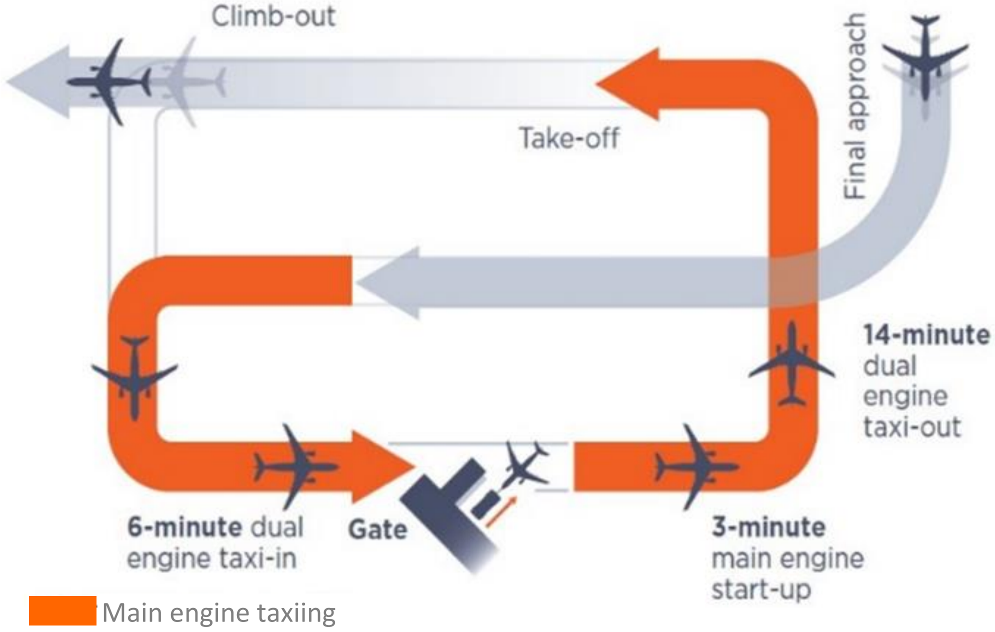

Figure 15: Main Engine-on footprint during LTO

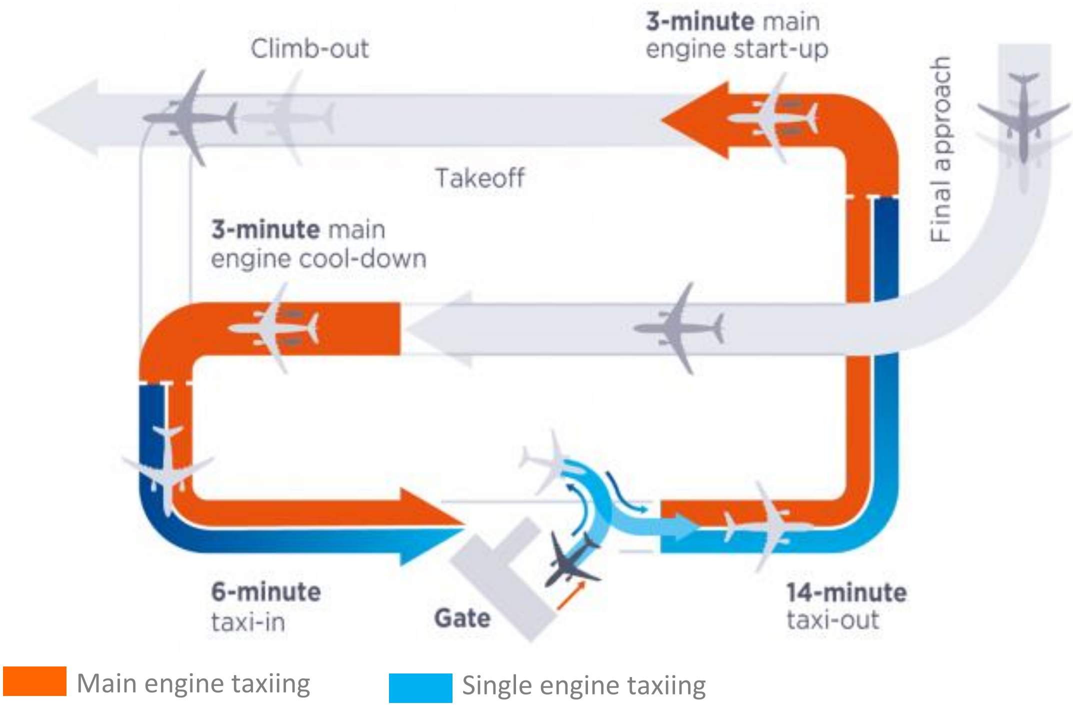

Figure 16: Single Engine-off footprint during LTO

3.3.1.4 Use of pre-departure sequencing tool

Figure 17 illustrates the pre-departure sequencing (PDS) tool, which constitutes a fundamental component of the Airport Collaborative Decision Making (A-CDM) process.

In order to achieve the best optimised airside-terminal operations, the real time sharing of information about various processes and aircraft positions are vital. 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.

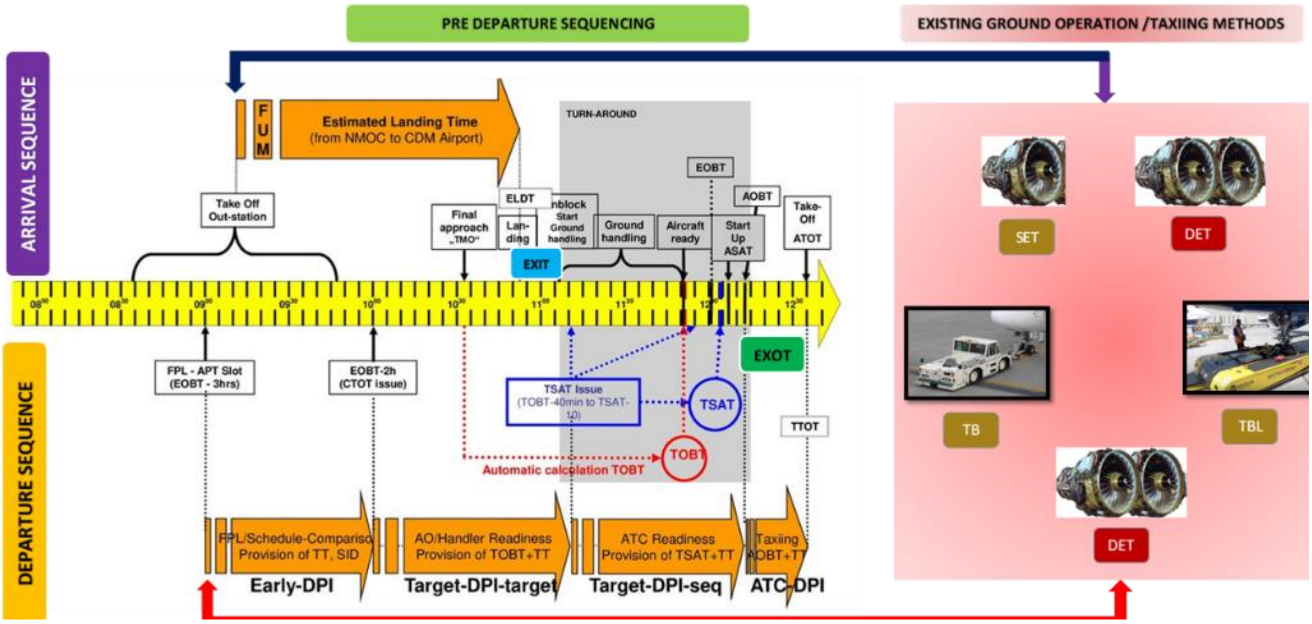

Figure 17: ACDM – PDS dashboard

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) as shown on the right-hand side of the figure. This option, if provided, would give an advantage to the airport in understanding their carbon footprint and local air quality. Prior to providing these options an airport specific safety risk assessment should be performed by the airport operator in order to analyse and adopt such taxiing methods into the PDS procedures. It would then enable the AO to choose the best taxiing methodology for a particular aircraft type, taxing time required etc. more explicitly, for both departure and arrival phases of an aircraft. These existing taxiing options does not much impact the PDS sequence in the current operation scenarios.

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 (indicated in grey box in Figure 17) along with the EXIT and EXOT times are key performance indicators for the efficient ground operations that are monitored using the A-CDM tool.

3.3.2 New AEON Operating Method

The various methods discussed under the new solution proposed by the AEON project have unique characteristic of operation.

As anticipated in section 3.1, the AEON operational concept moves from the consideration that in the future the different engine off techniques (single-engine, autonomous taxiing solutions and non-autonomous taxiing solutions) presented above may become robust technologies. In this future scenario there will be the need for them to coexist in the airport environment and to be used in a coordinated way thus overcoming the specific limitations that each of them has in the operations and pursuing the overarching purpose of making ground operations more sustainable and eco-friendly. In this sense, AEON does not consider their current limitations as a drawback for the concept.

Figure 18 and **Erreur ! Source du renvoi introuvable.** provide an integrated view of the CONOPS of both previous and new SESAR AEON operating methods. The conventional method such as DET of operation are compared with the AEON method of operation. It differentiates by defining the EXOT and EXIT phases and compares parameters such as fuel saving, noise, CO_2 emission and EXIT/EXOT times. The solutions described here are at different levels of product maturity, commercially developed by various manufactures. Although, there are more methods that could be integrated into the new SESAR solution, only few of them listed below are considered for this CONOPS. **It is to be noted that only generic terms are used to define the new solution.** The solutions defined here are:

- Non-autonomous taxiing techniques based on Dispatch Towing Vehicle Electric Taxi System (DTVETS)
- Autonomous taxiing techniques, referring to Nose & Main Landing Gear Electric Taxi System (NLGETS & MLGETS) and categorised under Landing Gear Electric Taxi System (LGETS)
- Single Engine Taxiing techniques (SET)

The above methods of taxing involve both external and on-board aircraft integrated systems that aid in delaying the start of aircraft engines by towing/powering them to a designated point near the runway on departure, while on arrival helps to quickly switch off the engine(s) partially or completely from a designated point.

Figure 18 shows the various actors who are involved in the ground operations. The EXOT phase begins from the apron with all engines off or on, single engine(s) on or by adopting the hybrid model as discussed earlier. The DTVETS, MLGETS and NLGETS are completely engine-off green taxiing methods till the cut-off point, where the engines are switched-on (during start-up & warm-up phase) depending on the situational awareness. However, the NLGETS method can also be used on a hybrid mode as shown in Figure 18. During the ground operation the ATCO, PIC and the Ground Staff are in constant communication with each other and transact Calls, Responses and Actions much like in the conventional method. The airports' role would be in augmenting necessary infrastructure to enable a seamless use of the new SESAR solutions, which in turn benefit them in optimised operation and environmental benefits.

Erreur ! Source du renvoi introuvable. shows the EXIT phase that begins from cut-off point, where the decision to taxi using engines on or off mode or operate by adopting the hybrid mode are decided by the PIC based on situational awareness and availability of the new SESAR solutions. The DTVETS, MLGETS and NLGETS are completely engine off green taxiing methods till the apron phase. However, the NLGETS method can also be used on a hybrid mode. During this phase of ground operations, the ATCO, PIC and the Ground Staff are in constant communication with each other and transact Calls, Responses and Actions much like in the conventional method.

The parameters compared for each solution are colour coded based on the efficiency of each parameter, ranging from <10 % (red) for being least efficient to >55% (dark green) for the most efficient.

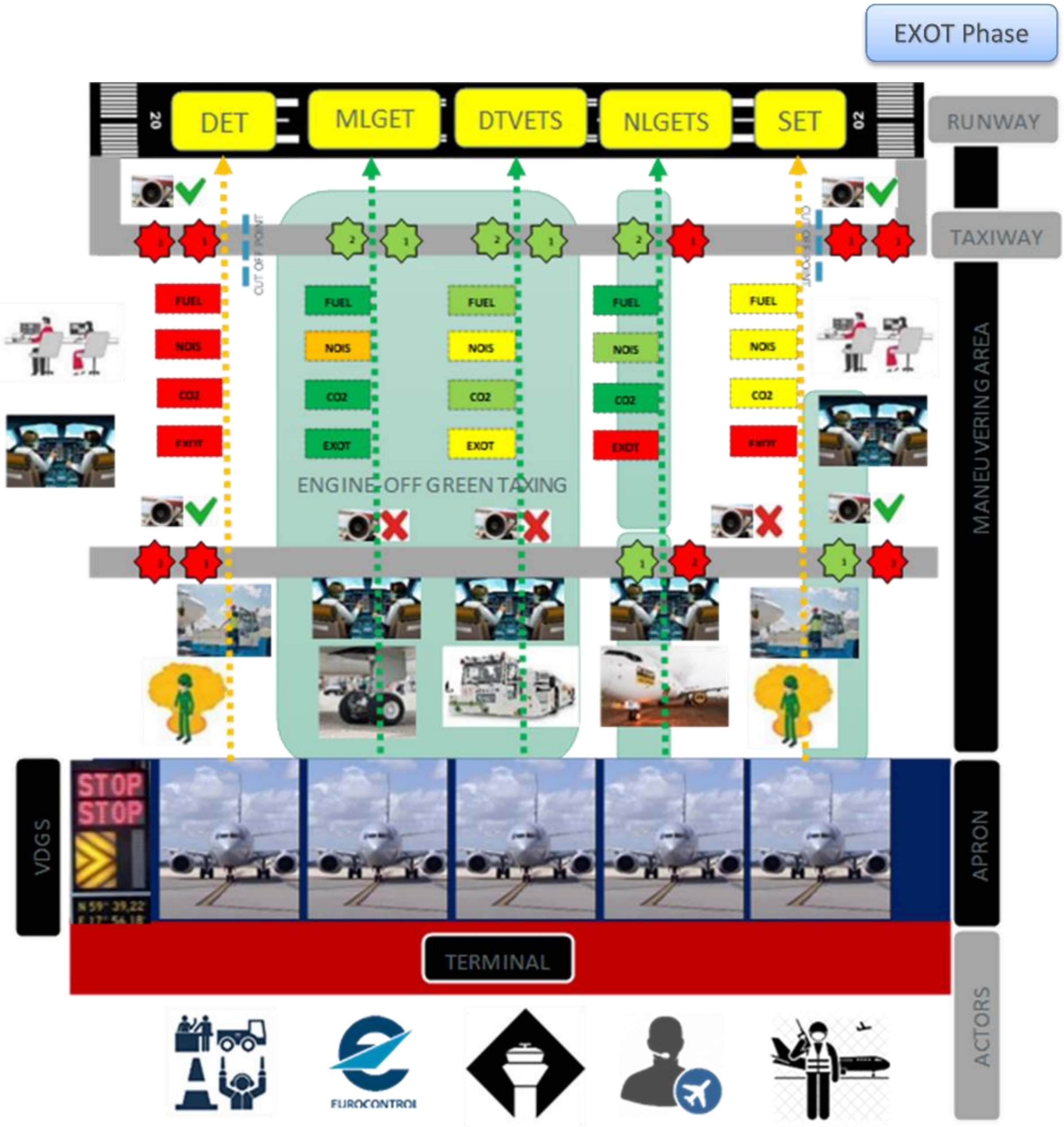

Figure 18: The new AEON Operating Method in comparison with the existing Operating method – EXOT / Departure Phase

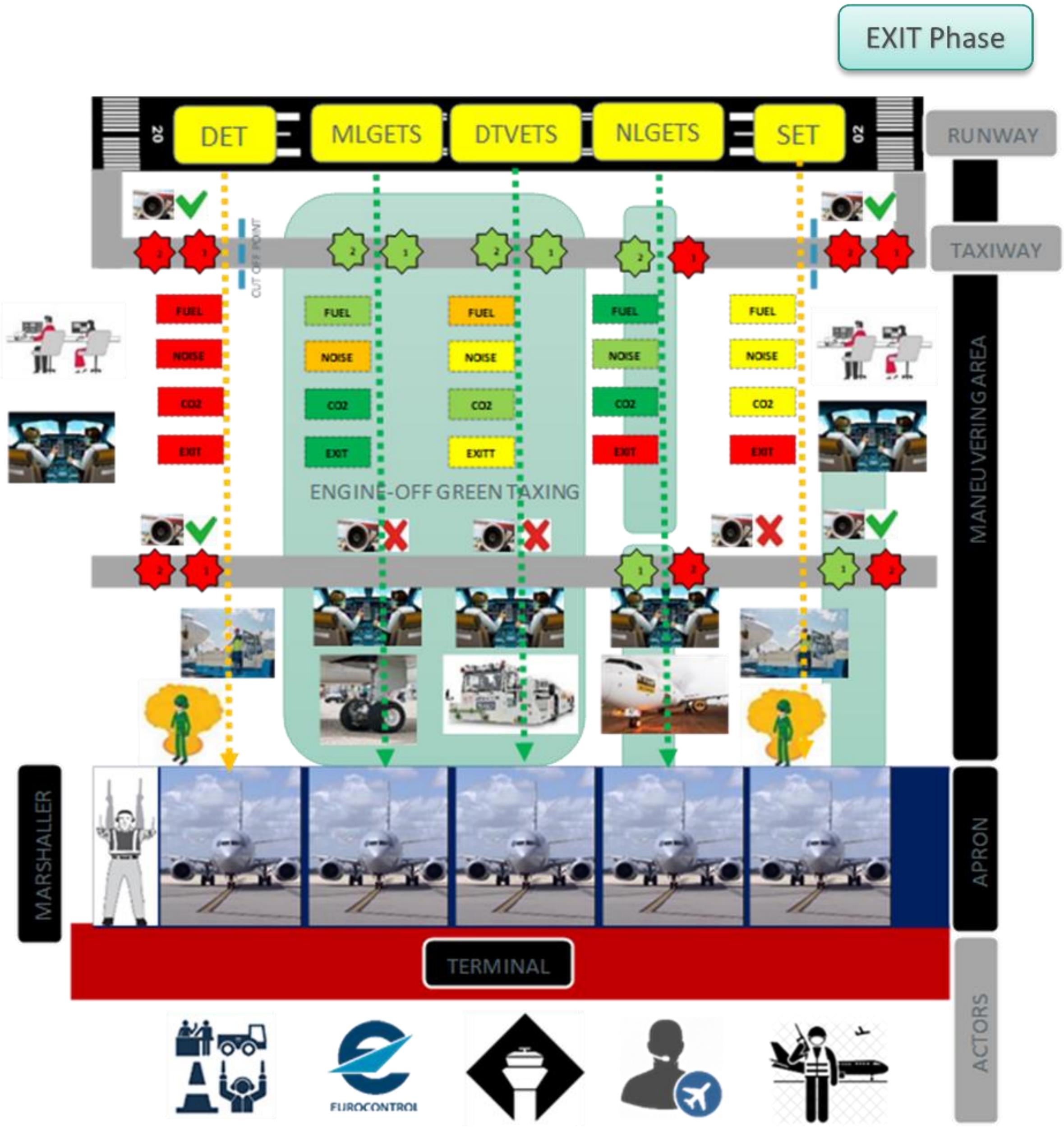

Figure 19: The new AEON Operating Method in comparison with the existing Operating method – EXIT / Arrival Phase

3.3.2.1 Dispatch Towing Vehicle Electric Taxi System (DTVETS)

3.3.2.1.1 Operation

The DTVETS System is a dispatch towing system that allows aircraft to taxi for departure to the runway end with engines off. 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.

As shown in the DTVETS CONOPS illustration in Figure 20, during the EXOT phase the pushback is performed in the same way as normal operations, however DTVETS is always in line with the aircraft. When the pushback is completed, controls are handed over to the pilot. Pilot control of the DTVETS is performed 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 DTVETS operates like a car with automatic transmission, accelerating when brakes are not applied.

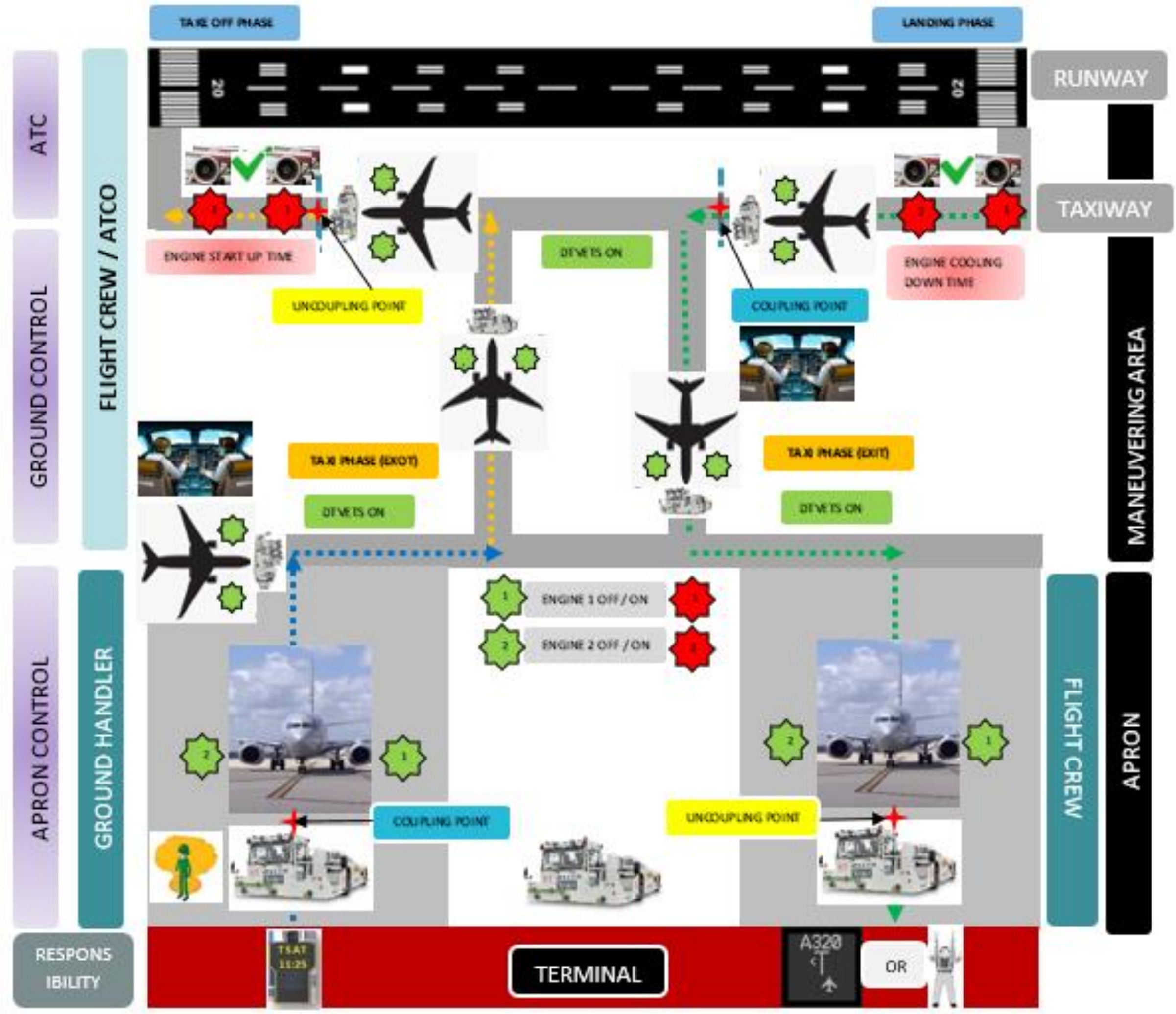

Figure 20: CONOPS diagram flow for DTVETS

The DTVETS tug also functions as an aircraft push-back tug.

Most aircraft require no modifications to use of DTVETS. Taxi operations with this innovative system are essentially transparent to the pilot by allowing the PIC to steer the aircraft using the DTVETS through the aircraft tiller while controlling speed through the normal aircraft brakes. As shown in Figure 20 an aircraft coupled to a DTVETS performs taxiing (DTVETS ON) in the same manner as an aircraft moving under its own power, with the aircraft auxiliary power unit (APU) supplying 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.

The DTVETS is envisioned for both EXIT and EXOT phases.

As illustrated in Figure 20, once the DTVETS is attached at the "coupling point" on the apron and cleared for "delivery" by the GC to the GS/FC, the DTVETS will push the aircraft back from the gate/stand in the same manner as it is done today under the direct responsibility of the trained DTVETS driver. Once pushback is completed, the control would then be transferred/switched to PIC and the FC can begin DTV taxi movement (DTVETS ON) till the disconnect point or uncoupling point/area where the aircraft engines can be started while being connected to DTVETS based on the situational awareness, closer to the assigned runway end. Once uncoupled and the control switches to the DTVETS driver, the tug is driven back in the manoeuvring areas of the airport to the next operation.

On arrival, the aircraft can use the DTVETS technology as shown in Figure 20. The assigned DTVETS tug will be stationed at an area close to the runway/taxiway designated point as per AOP and once the aircraft reaches the designated coupling point, the DTVETS driver would attach the tug to the aircraft nose wheel and transfer or switch control to the FC for DTV taxi movement. During this phase of coupling the PIC can decide to switch off the engines and allow them to cool down during the DTVETS coupling and control handover process is taking place. Once the DTVETS is attached, the FC can steer the aircraft to the gate / parking stand with engines off. Upon reaching the parking stand the PIC can uncouple and transfer back the control of the tug to the DTVETS driver, who in turn can position the tug for its next assignment.

A typical "pushback/engine off and late start-up departure procedure" for DTVETS along with actions taken by various accountable stakeholders are listed in Table 2.

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 DTVETS	DTVETS driver
5	Ground ready call	DTVETS driver
6	Clearance for push-back	Apron Controller (AC)
7	Pushback clearance to driver	Pilot
8	Perform pushback	DTVETS driver
9	Switch to pilot (control) mode	DTVETS driver
10	Confirm pilot mode	Pilot
11	Ready to taxi signal	DTVETS driver
12	Taxi instructions to pilot	Ground Controller (GC)
13	Taxi out to uncouple location	Pilot
14	Uncouple DTVETS	DTVETS driver
15	Start-up engines	Pilot
16	All clear signal	DTVETS 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 2: Action taken and accountable stakeholder for departure procedure

A typical "driveback procedure" for DTVETS along with actions taken by various accountable stakeholders are listed in Table 3.

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

Table 3: Action taken and accountable stakeholder for drive back procedure

A typical "Arrival/engine off procedure" for DTVETS along with actions taken by various accountable stakeholders are listed in Table 4.

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

Table 4: Action taken and accountable stakeholder for arrival procedure

The DTVETS operation can 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 the DTVETS method of taxiing.

It is seen that, out of the 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. Similar savings can be achieved during engine-off and cooling down operating cycle, while the DTVETS pulls the aircraft (controlled by the FC) to the parking stand/gate during taxiing-in phase.

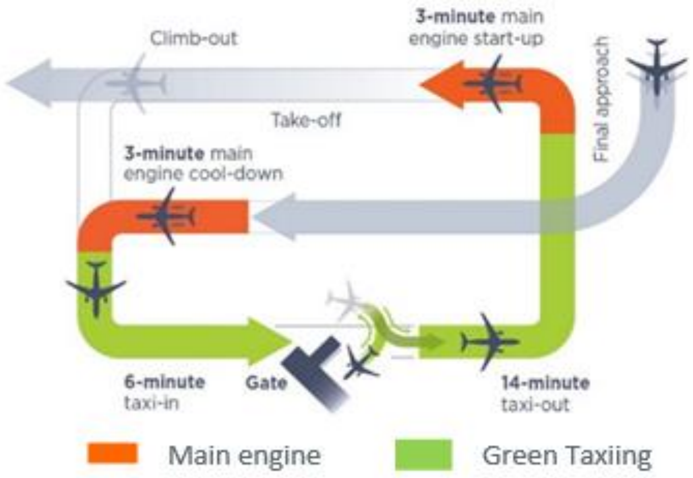

Figure 21: DTVETS Engine-off footprint during LTO cycle

3.3.2.1.2 DTVETS nominal workflow

Taxi technique allocation is discussed between the ground operations actors through A-CDM application. The envisaged nominal workflows for each technique are summarised in the following figure:

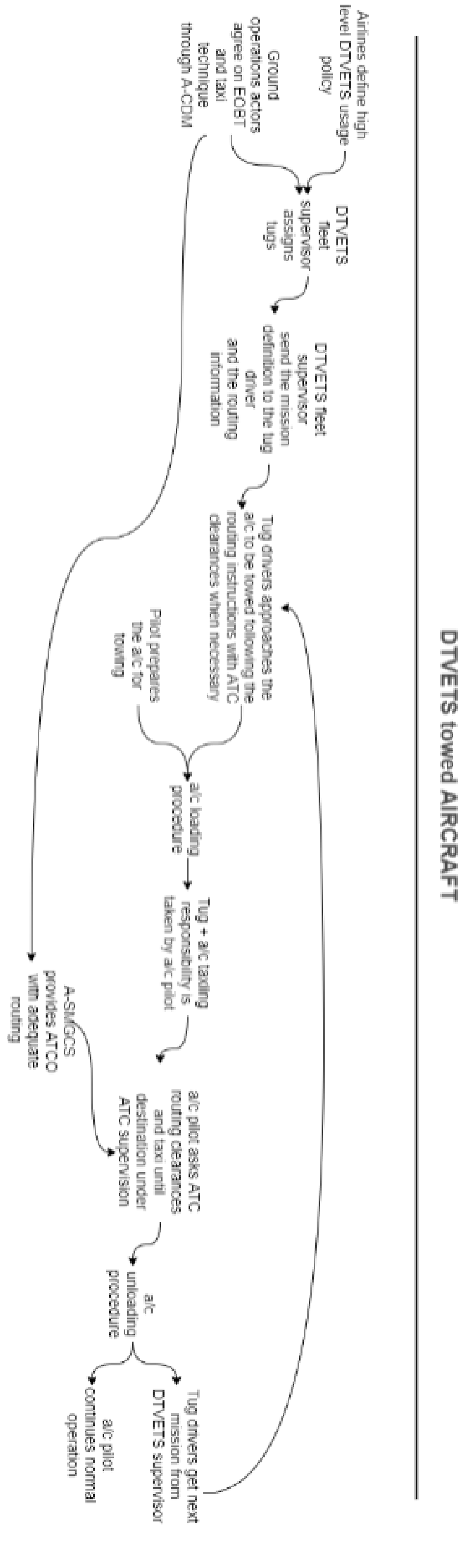

Figure 22: DTVETS nominal workflow

3.3.2.1.3 Fleet Management

Depending on the economical model applied, the DTVETS operation 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 operated either by APTO or Ground Handling, but AO could also have its own vehicles.

In the CONOPs procedure, it is assumed that the DTVETS tugs are well maintained and operated by the APTO/AO/GH at all times and the entire fleet management responsibility rests with the DTVETS fleet manager.

The DTVETS fleet manager 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. The DTVETS manager will be in charge of providing towing vehicle on time for the towing operation to be performed as requested. In particular, the manager will have to choose and assign the towing vehicles to the a/c to be towed, supported by dedicated algorithms for allocating vehicles to specific aircraft and identifying efficient routes to follow. Once the mission is assigned, it becomes the DTVETS operator and ATCO joint responsibility to reach the a/c to be towed on time for smooth operations.

3.3.2.2 Landing Gear Electric Taxi System (LGETS)

The Landing Gear Electric Taxi System (LGETS) is an on-board innovative in-wheel electric taxi system with electric motors integrated in the nose wheel – termed as Nose landing gear electric taxi system (NLGETS) or in the main landing gear – termed as Main landing gear electric taxi system (MLGETS). 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 LGETS 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.

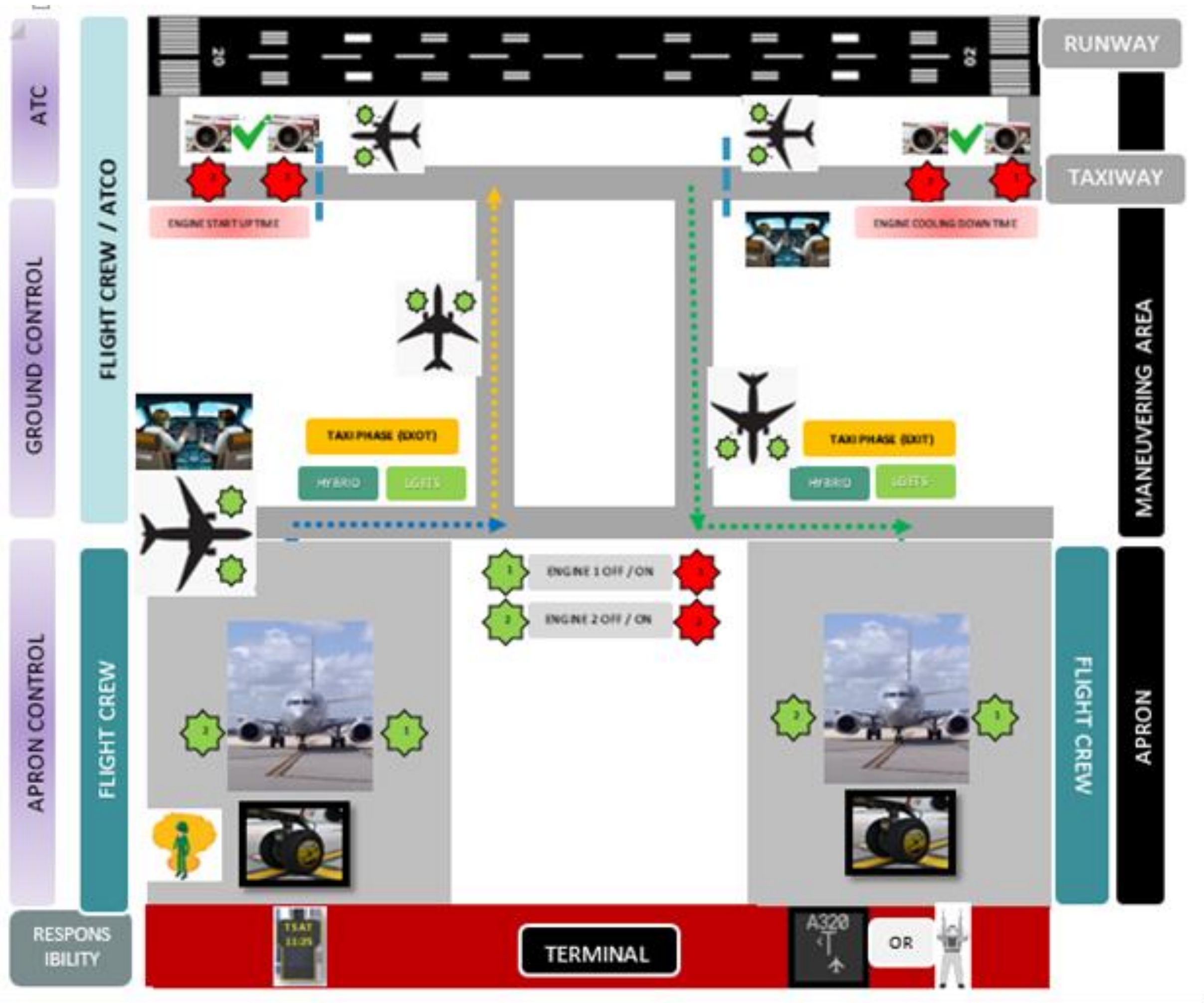

Figure 23: CONOPS diagram flow for LGETS

The LGETS fitted aircraft 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 will positively influence risk and improve risk mitigation. However, gaining experience in daily operation is needed in order to perform a risk assessment and start a re-definition analysis.

In order to avoid misunderstandings, the term "*wheelback*" will be introduced 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 (Figure 23). **The main difference seen on ground operation is the shift of responsibility for pushback (or *wheelback*) from the Ground Staff to the PIC, during normal operations.** Once the GS confirms the ground is ready for *wheelback* (or pushback), the PIC confirms the use of on-board LGETS operation 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 of the LGETS is then performed 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 LGETS mode (Figure 23) or follow the Hybrid mode as shown in Figure 24.

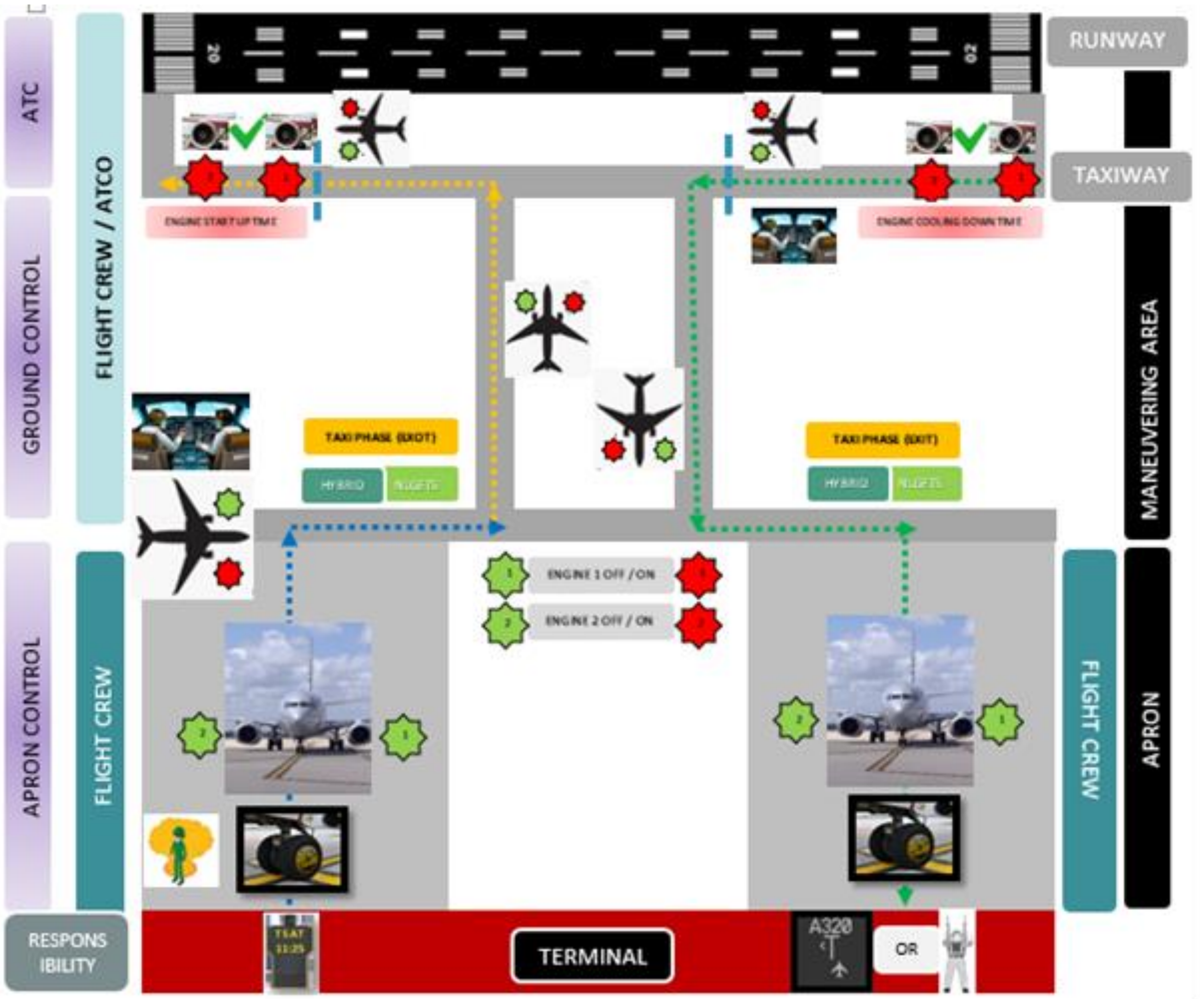

Figure 24: CONOPS diagram flow for HYBRID flow using NLGETS

Aircraft will be able to operate in a hybrid mode, where the e-taxi system is engaged, and one engine is engaged in idle to support breakaway in stop-and-go situations as shown in Figure 24.

It is important to note here that, out of the LGETS methods of operation, the NLGETS technology has a speed limitation of 9 Knots/ hour on the ground. It is for this reason that aircraft on board with NLGETS may adopt a hybrid mode of operation to gain speed during taxiing. The PIC/AO have the complete flexibility to operate the aircraft either on NLGETS or Hybrid mode based on need, regulation and slot requirements.

Aircraft with MLGETS technology on board can achieve speed up to 20 Knots/hour, which is considered as the optimal taxing speed on the airfield. In order to maximise the efficiency (both in terms of cost and other environmental benefits) it is good to operate an aircraft on board with MLGETS with all engines off. At the same time, it does not prevent the aircraft using the MLGETS to operate on a hybrid mode if situation demands.

In the event of a Hybrid mode of operation, wherein the PIC decides to start-up the engine (in this case single engine), the aircraft can be taxied using both NLGETS and SET to the taxiway holding point close to the runway, based on the speed limitations. During the Hybrid mode of operation, the NLGETS system also shift modes to either electric (when the speed of the aircraft moves below 9 knots) and 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 LGETS mode of operation along with actions taken by various accountable stakeholders are listed in Table 5.

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 Wheel-back	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 NLGETS and/or using Hybrid option	Pilot
11	Taxi out to runway	Pilot
12	At runway transfer aircraft to Air Traffic Controller	Ground Controller (GC)

Table 5: Action taken and accountable stakeholder for LGETS operation

Figure 25, Figure 26 and Figure 27 illustrate the LTO cycle using the NLGETS, Hybrid and MLGETS method of taxiing.

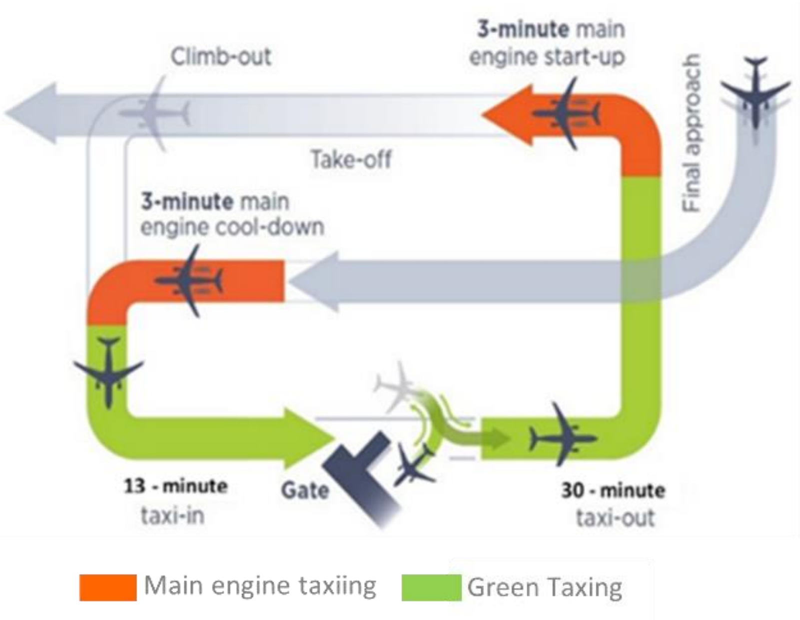

Figure 25: LTO cycle for NLGETS operation

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 LGETS methods, as illustrated in their respective LTO cycles.

As evident from Figure 25, the time taken during the taxi-out phase using the NLGETS 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 achieved using NLGETS technology. 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 26 shows the Hybrid way of operating NLGETS taxiing, 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 option, till the a/c reaches the gate /parking stand. We can notice that the taxi times have reduced compared to the NLGETS option in both EXIT and EXOT phases due to required speed achieved using the hybrid mode of operation.

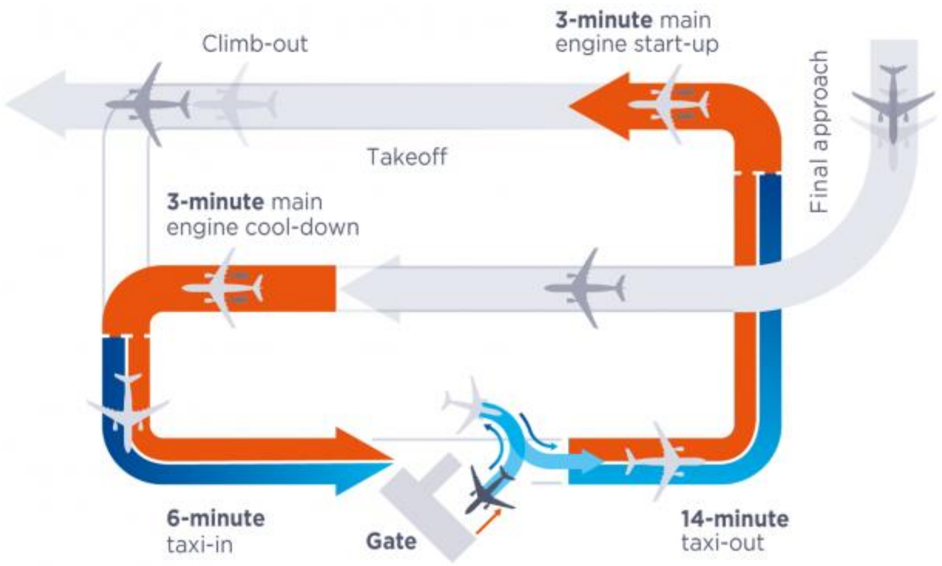

Figure 26: LTO cycle for NLGETS hybrid operation

Figure 27 shows the taxiing operation using MLGETS method, 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 NLGETS option, but other parameters such as fuel, noise, CO2 emission have gained maximum reductions.

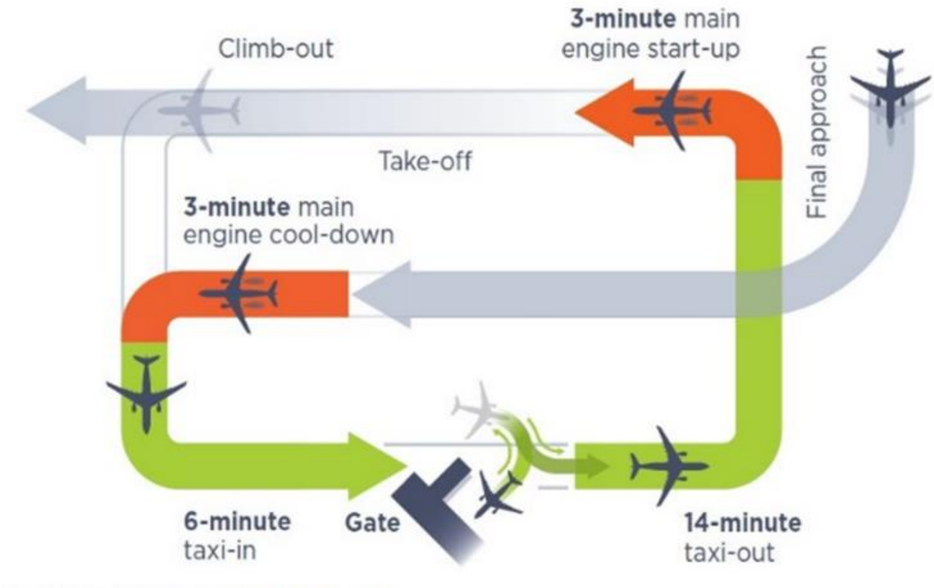

Figure 27: LTO cycle for MLGETS operation

3.3.2.3 Single Engine Taxi (SET)

The SET or Single Engine Taxiing is the new norm of operations that is followed specially by low-cost airline carriers, for obvious reasons. Airports have not regulated or formulated a procedure specifically for the single engine taxing as it is felt that all engines-on existing procedures would cover for most of the risks involved in SET. In some cases, this may not be true, as single engine may need to offer more thrust to operate the aircraft than the distributed thrust offered by all engines, which in turn may impact the risk associated on the airport infrastructure (i.e., jet blast). For this reason, a detail risk assessment study would need to be carried out by the respective airport operator in order to identify, analyse and incorporate adequate safety measures for use of single engine taxiing, both during the EXIT and the EXOT phases of aircraft operations.

In SET, both the departure and arrival procedures follow a similar sequence of activities that the current operations do at the airports, except for that 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 / off engine 1 or 2 (in case of Narrow Body – NB – aircraft) or 1-3 and 2-4 (in case of Wide Body– WB – aircraft) would 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.

Figure 28 illustrates the concept of operation for single engine taxi method. Once or during the push back operation the Flight Crew switches on the engine and gets ready for taxi based on Ground Controller's approval. Upon reaching the designated hold point near the runway the PIC may decide to start the second engine(s) and complete all the pre-departure checklists or based on the traffic line up wait and do a delayed start so as to save fuel/CO_2 emissions to the maximum extent. On Arrival, the PIC can decide to switch off the engine and taxi using single engine to the designated apron parking stand. However, based on the Airport Operating Plan (AOP) if there are any restrictions imposed on certain portions of the airside infrastructure that would impede the use of SET, then the AO in coordination with the airport operator/ ANSP should redefine and publish Notice To AirMan's (NOTAM) accordingly.

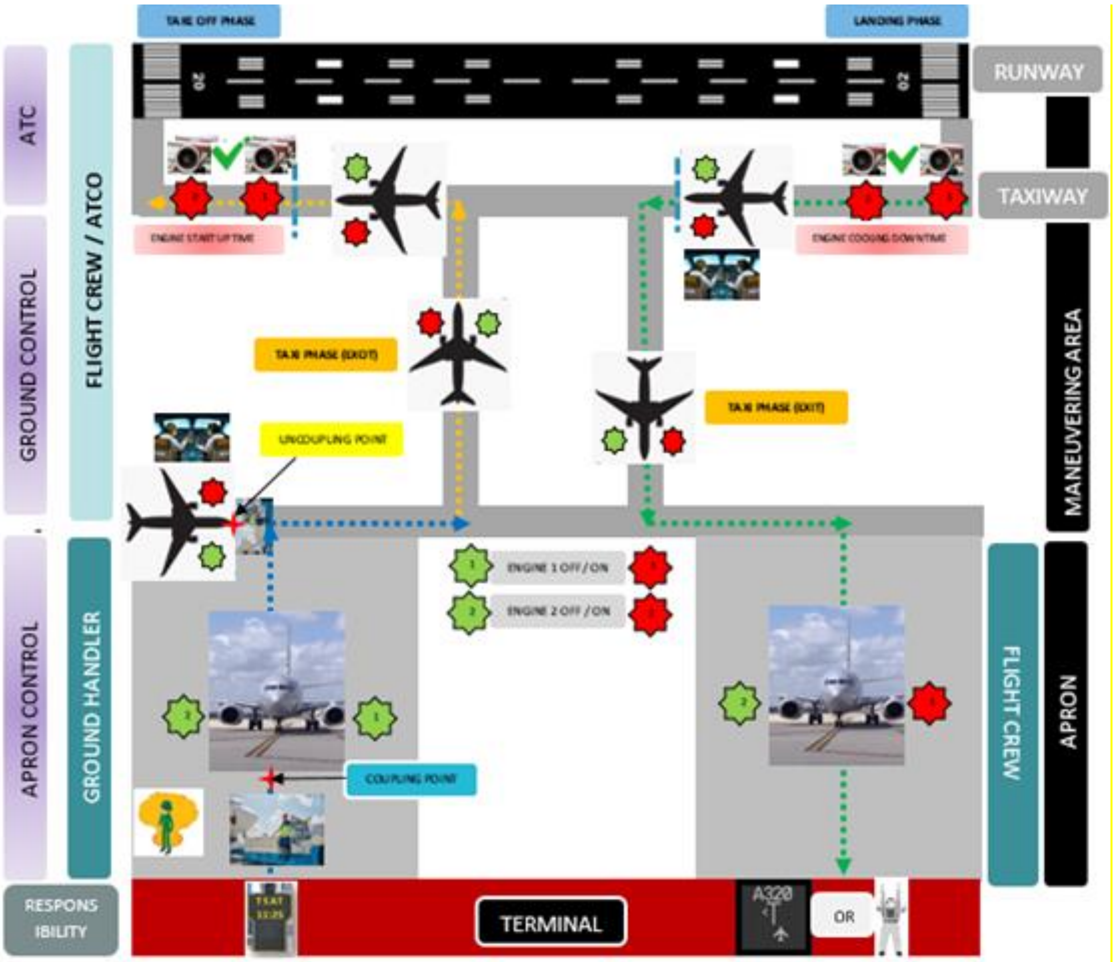

Figure 28: CONOPS diagram flow for Single Engine

A typical "pushback/single engine off and late start-up departure procedure" for SET along with actions taken by various accountable stakeholders are listed in

Table 6.

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 push-back	Apron Controller (AC)
7	Pushback clearance to driver	Pilot
8	Perform pushback	Tug driver
9	Start-up engine (single)	Pilot
10	Detach Tug from the aircraft	Ground Staff (GS)
11	Confirm "All Clear" / Ready to taxi signal	Ground Staff (GS)
12	Taxi instructions to pilot	Ground Controller (GC)

Step	Action outbound	Action from
13	Single Engine Taxi to hold point location	Pilot
14	Start-up of second engine (warm-up)	Pilot
15	Ready call - for lineup and take off	Pilot
16	At runway transfer aircraft to Air Traffic Controller	Ground Controller (GC)

Table 6: Action taken and accountable stakeholder for SET operation

Figure 29 illustrates the LTO cycle using the SET method of taxiing. It is evident that, out of the 14min of taxi-out time, the single engine-off phase can be for about 10-11 min, while about 3-4 min are used for second engine-start up procedures. Similar timeframe can be used to switch off and cool down one set of engine(s) while using SET method, till the aircraft reaches the parking stand/gate during taxi in phase.

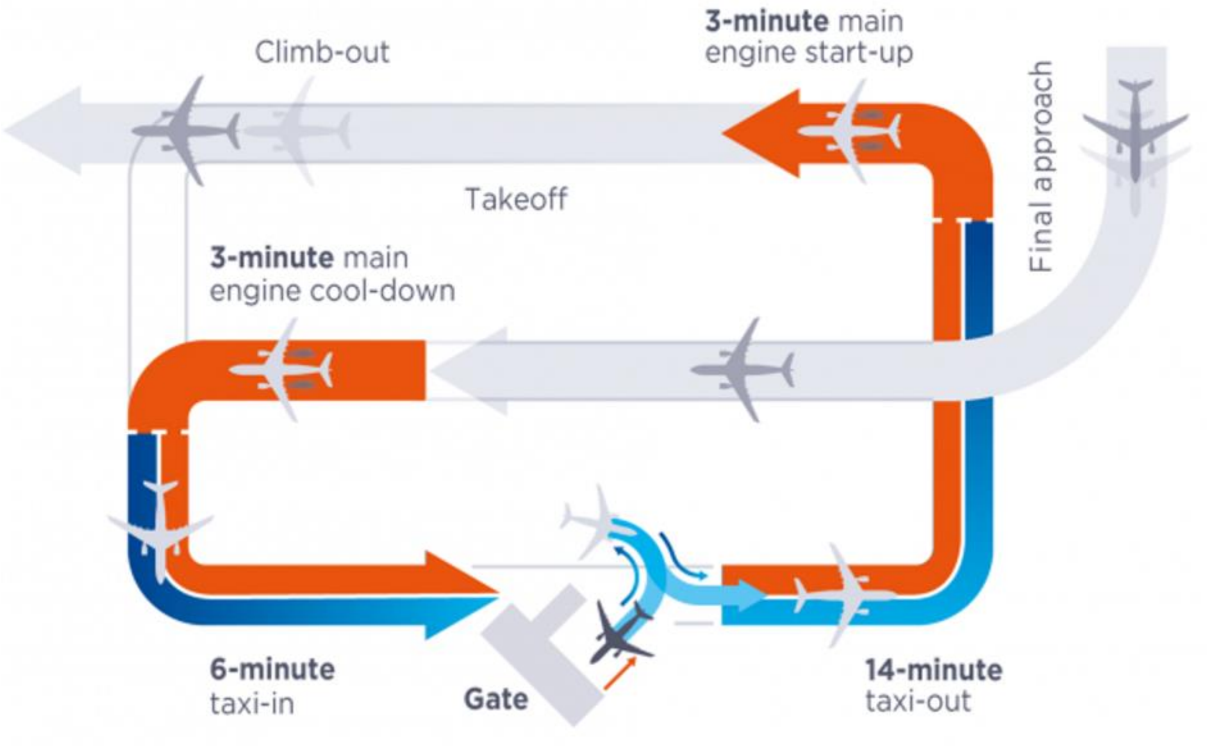

Figure 29: Single Engine-off footprint during LTO

3.3.2.4 Integration of new SESAR solution into A-CDM

Erreur ! Source du renvoi introuvable. illustrates the new pre-departure sequence (PDS) tool that is envisaged to be integrated with the AEON concepts of operation in providing engine-off options to aviation stakeholders who use the Airport Collaborative Decision Making (A-CDM) platform. In order to achieve the best optimised use of engine-off techniques, the AO/GH are provided with real time fleet availability (DTVETS) or internal on-board system availability (NLGETS, MLGETS 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.

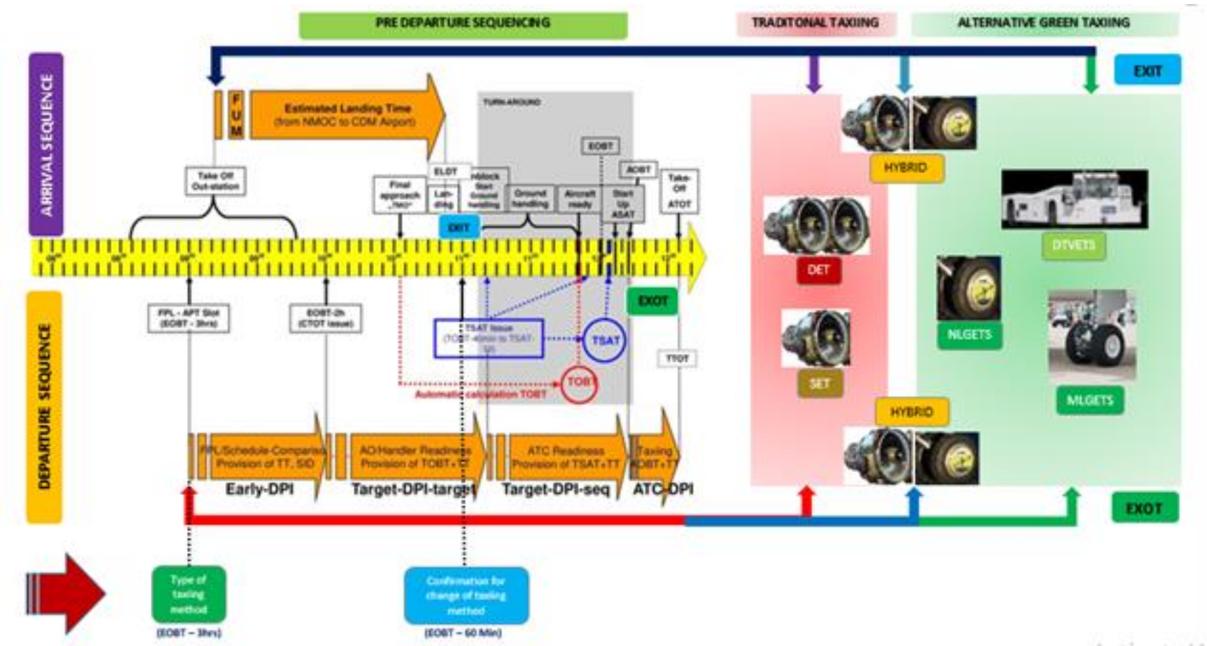

Figure 30: Integrated ACDM – PDS dashboard

As per **Erreur ! Source du renvoi introuvable.** the AO/GH can file their flight plan 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 new PDS platform should provide operation to the AO/GH to choose and update their preferred possible taxiing technique as shown on the right-hand side of **Erreur ! Source du renvoi introuvable.**. These options give an advantage to both the airport and the airline 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 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.

3.3.2.5 Traffic scenario

Based on operational experience and industry data, the traffic mix and alternative taxi use are defined as shown in Table 7 below.

Traffic Mix & Alternate Taxi Use: Outbound flights

Terminal	Traffic Mix	Peak Hour Traffic mix	Narrow Body	Wide Body
Terminal - 1	9%	7	7	0
Terminal - 2	60%	46	15	31
Terminal - 3	25%	19	19	0
Cargo Terminal	5%	4	0	4
Total	100%	76	41	35

Terminals	Conventional Pushback + DET	Conventional Pushback + SET	Wheel Tug Operation	TaxiBOT Operation	EGTS (MLG Operation)	Wheeltug + SET	Total
Terminal - 1	1	1	1	4	0	0	7
Terminal - 2	5	7	8	23	1	2	46
Terminal - 3	2	3	3	10	0	1	19
Cargo Terminal	1	1	0	2	0	0	4
Total	8	11	12	39	2	4	76

Table 7: Peak Traffic mix of flights - Terminal wise – AEON method wise (Outbound)

The tables illustrate that, there is an outbound aircraft traffic of 76 flights and an inbound traffic of 72 flights assumed for a busy hub airport with traffic emanating from three passenger terminals and one cargo terminal. The peak hour traffic mix is divided aircraft category wise (narrow body or wide body) depending upon the Origination-Destination parameters, airlines and type of traffic at the airport. The third variable considered in the use case is the use of new operating solutions or alternate taxi use comprising of SET, DTVETS, NLGETS, MLGETS and NLGETS Hybrid options respectively.

Traffic Mix & Alternate Taxi Use: Inbound flights

Traffic Mix	Terminal Mix	Peak Hour Traffic mix	Narrow Body	Wide Body
Terminal - 1	9%	7	7	0
Terminal - 2	61%	44	15	28
Terminal - 3	25%	18	18	0
Cargo Terminal	5%	4	0	4
Total	100%	72	40	32

Terminals	Conventional DET	Conventional SET	Wheel Tug Operation	TaxiBOT Operation	EGTS (MLG Operation)	Wheeltug + SET	Total
Terminal - 1	1	1	1	4	0	0	7
Terminal - 2	3	7	7	23	1	2	44
Terminal - 3	1	3	3	9	0	1	18
Cargo Terminal	1	1	0	2	0	0	4
Total	6	12	11	38	2	3	72

Table 8: Peak Traffic mix of flights - Terminal wise – AEON method wise (Inbound)

For the purpose of this study and in reality, a transition phase is required to be considered in adopting these technologies and completely moving away from the conventional methods. It is for this reason the DET method is considered to understand the impact on the operations, capacity etc.

These variables can be altered and used to test the scenarios and arrive at results that best fits the airport on the test case.

The scenarios described illustrates the limit and the flexibility of the use of new operating method of taxing at any airport. The choice of use of a particular operating method at EOBT – 3 hours or 180 min and at every update of TOBT provides the flexibility to the AO/GH in choosing the best optimal solution for their aircraft. At the same time, the limit to which the operating method can be, allowed a change, by not straining the resources of the airport or the GH is also the scenario to be tested in order to efficiently plan the tug fleets at the airports.

3.3.2.6 Use cases

A number of use cases are presented to illustrate the AEON concept in a set of selected and realistic operational situations that could arise at any commercial airport environment.

Erreur ! Source du renvoi introuvable. shows the new PDS procedure (in short PDSP) adopted (during the PDS-ACDM process) to input, update or revise the new SESAR solutions.

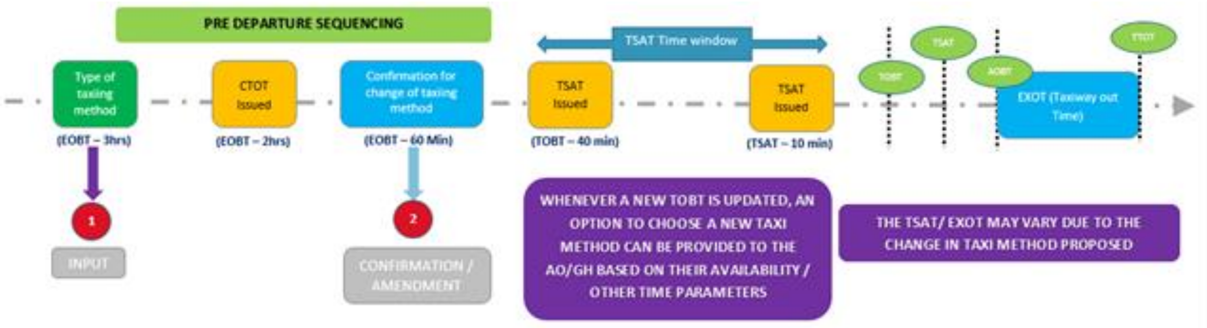

Figure 31: The new pre departure sequencing procedure (PDSP)

The new pre departure sequencing procedure (PDSP):

1. If the taxing method requested at EOBT-180 min remains the same at EOBT-60 min as shown in **Erreur ! Source du renvoi introuvable.**, then there no need to re-confirm the methodology of taxing. Only if there is a change required by the AO/GH or there is an alert raised due to failure / delay associated with the technology provided and the AO/GH wishes to change the taxing method, then the same can be re-confirmed at EOBT-60 min, as shown in

2. If one particular taxing method becomes unavailable (for any reason) after EOBT – 60 min and before TOBT, then the AO/GH has the following options:

    a. Request for alternative green taxing method that may not potentially affect the TOBT/TSAT.

    b. If TOBT is affected then, while filing the revised TOBT, choose also the available taxing method so that a revised TSAT would be issued.

    c. If 2(a) OR 2(b) would fail to fulfil the AO's requirement, then based on the agreement / availability at the airport or with the GH, a conventional pushback and a Single Engine Taxi (SET) procedure can be adopted.

    The changes of the taxing method may occur due to:

    1. non-availability of the taxing method at EOBT-180min and availability at EOBT-60 min.

    2. availability of the new taxing method at EOBT-180min and decision to change by AO/GH at EOBT-60 min.

The availability of the new taxing method (such as DTVETS) at EOBT-180min and non-availability at EOBT-60 min may come from the fact that the DTVETS is not released by the preceding aircraft due to airside delays/failure. An alert message may be generated at EOBT-60 min to inform the AO/GH regarding the delay and the potential non-availability of the technology. The AO/GH can then follow Step 2 of the PDSP.

SCENARIO – 1: Change of use of alternate taxing method:

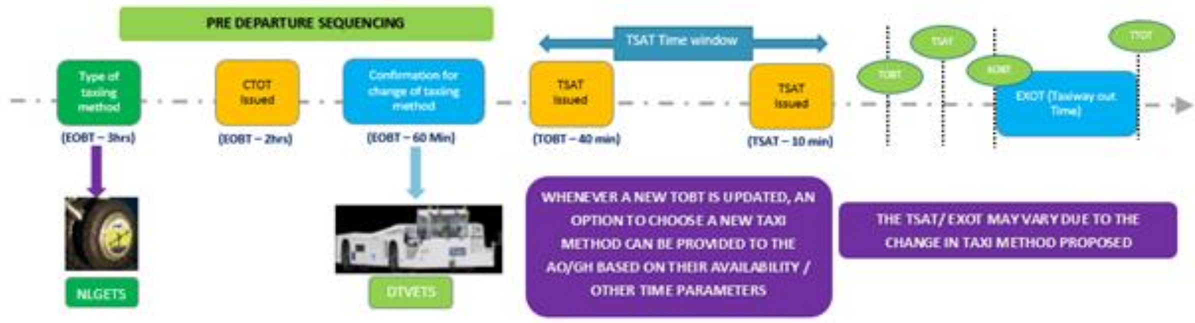

Figure 32: SCENARIO 1 - Change of use of alternate taxing method

Assumed scenario conditions:
A departing flight is equipped with NLGETS and planned to use it. At EOBT – 60 min the taxi method is modified by the airline after a malfunction is discovered on the NLGETS system. DTVETS is chosen instead and since a tug is free at push back time, the estimated taxi time is not updated but the new time allows the same TSAT and TTOT so the choice is validated and all stakeholders share the information.

SCENARIO – 2: AD-HOC delay due to missing passenger/ delay in aircraft (TOBT delay)

Assumed scenario conditions:
A flight is departing at 20:00 (i.e., Flight Plan EOBT).
The flight from the airline side is running perfectly on time up until 19:50 when a passenger is missing, and baggage has to be removed off the flight.

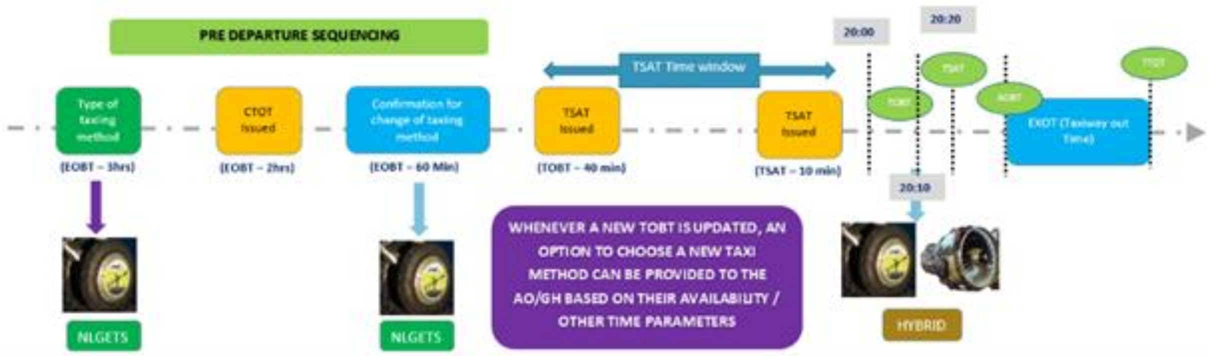

Figure 33. SCENARIO2 - AD-HOC delay due to missing passenger/ delay in aircraft (TOBT delay)

In scenario 2, the initial TSAT has been issued based on the taxi technology selected. To cover up the last-minute delay caused by the missing passenger, the AO/GH can change the methodology by filing the new one that is more performant and gives a shorter taxi time. In this case however the taxi time computation shows that the TSAT can be reached without changing the taxi technique. Otherwise depending on the taxi type chosen an additional delay could come from external device use. In the event, external device needs to be connected/used (due to the chosen technology) that may potentially delay the TOBT, then the AO/GH can follow Step 2(b) of PDSP and a potential new TSAT could be issued.

<u>SCENARIO – 3: Regulated (CTOT Allocation)</u>

Assumed scenario conditions:

1. the flight is departing at 20:00. The flight from the airline side is running perfectly on time.
2. There is a flow control restriction, and the flight is assigned a CTOT at 21:40 creating a difference between TOBT and TSAT that is more than 60 minutes.

When this delay occurs, the AO/GH can proceed according to two alternatives:

1. Maintain Boarding Process - Continue the turnaround process and aim to be ready at TOBT or:
2. Delay Passenger Boarding - Decide to delay passenger boarding and update the TOBT accordingly to a new time ensuring they are ready in due time not to miss the TSAT and CTOT.

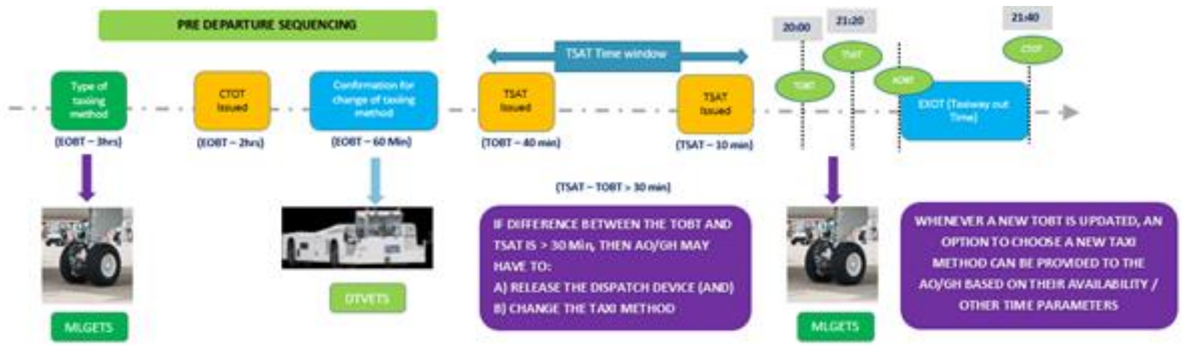

Figure 34. Scenario 3 – Traffic regulated (CTOT Allocation)

In the scenario 3, the CTOT is assigned in such a way that the difference between TSAT and TOBT is more than 60 min. The chosen taxi methodology (other than external dispatch devise – in this case DTVETS) may be continued as their preferred option. In the event, the difference between TOBT and TSAT is more than 30 min, and the AO/GH has chosen an external dispatch devise (DTVETS), then the same may not be blocked by the AO/GH and be released for use by other operators. In any case while filing the revised TOBT, the taxi methodology can be chosen (based on the availability) so that the TSAT and CTOT are not missed by following Step 2 of PDSP.

3.3.3 Differences between new and previous Operating Methods

From the descriptions of the current operating methods provided in section 3.3.1 above, it is evident that in the current scenario the three taxing techniques taken into account are considered as individual techniques. Conversely, the introduction of the AEON concept of operations implies a more systemic and coordinated approach that tends to integrate the three taxing techniques and thus requires different and specific roles and operating methods, as described in section 3.3.2.

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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.

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 really 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 activity:

- In order to achieve the best optimised use of engine-off techniques, the AO/GH are provided with real time fleet availability (DTVETS) or internal on-board system availability (NLGETS, MLGETS 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 is intended to enable the A-CDM platform to calculate the TSAT for the said aircraft and to defined fixed coupling and decoupling points for aircraft associated to DTVETS. This specific feature of the AEON concept is expected to largely affect the work of AO and GO.

- **DTVETS Fleet Management** - The DTVETS fleet manager 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 is able to 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.

These differences reflect into the specific operating methods of the concerned actor, for which a need for additional and dedicated training has been identified. It is worth noticing that at this stage of the project the operating methods are defined at high level, and a more detailed version is expected to be included in the final version of this document that will be issued at the end of the project.

Activities (in EATMA) that are impacted by the SESAR Solution	Current Operating Method	New Operating Method
Strategic planning	The A-CDM helps achieve the best optimised airside-terminal operations without taking into account the specific techniques used for taxing	In AEON a new HMI interface is designed and prototyped, capable to integrate various e-taxing solutions into one dashboard that supports their allocation. During this phase airlines and ground handlers receive information about DTVETS allocation and can accept/reject/change it up to 1-hour before take-off/ landing. They can also define the taxiing techniques

		assigned to the rest of the traffic if not all the traffic is assigned DTVETS. Need for specific training.
DTVETS fleet management during the tactical planning phase	This role does not exist in current operations	The fleet manager receives the allocation DTVETS/aircraft and manages the fleet accordingly. S/he also changes the allocation in case of delays/problems in respecting the plan. The allocation feeds the path planning algorithm. Need for specific training.
Aircraft towing by DTVETS	This role does not exist in current operations	Tug drivers receive instructions about the DTVETS allocation of each a/c and the specific path to be followed. They are also informed about coupling and de-coupling points. They promptly inform the fleet manager in case of delays or problems in matching the plan. Need for specific training.
Ground an apron air traffic management	Define the taxiing path of each aircraft and monitor the execution of clearances	The ground and apron ATCOs receive the information about the taxiing technique assigned to the aircraft and the path to be followed and are in charge of providing clearances to pilots and monitor. Need for specific training.
Taxiing	The pilots receive the taxiing clearances and follow them	The pilots follow instructions about the taxiing techniques to be used and the path to be followed, including coupling and decoupling and engine warm-up ad cool down. Need for specific training.

Table 9. 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)
- Performance (PR)
- 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

4.1 ATM operational requirements

4.1.1 Airport minimal requirements

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A-SMGCS is divided into 4 services[10]:

1. Surveillance service includes 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[12]:

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	AEON targets airports of group 1 and 2, equipped with an A-SMGCS with at least surveillance and routing services.
Status	In progress
Rationale	
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 an other mean) to airlines information about taxi techniques planned for each aircraft to provide this information to routing services (RM).
Status	In progress
Rationale	
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-UU01.0003
Title	Aircraft information
Requirement	An airport that implements AEON concept shall have an 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 an access to the in bound 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

4.1.2 Strategical 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 should be provided to all stakeholders.
Status	In progress
Rationale	Providing ecological key performance indicators to stakeholders will increase the chances of ecological decisions when possible.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-CD01.0001
Title	A-CDM application taxi technique choice
Requirement	The A-CDM application should allow the stakeholders to define in advance the taxi technique for each departing aircraft. It has an impact on the TOBT and the organisation of ground handling activities.
Status	In progress
Rationale	
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-CD01.0002
Title	A-CDM application interface

Requirement	A-CDM should use the initial tugs allocation plan computed by the Tugs allocation module in order to prefill the taxi technique choice.
	• Inputs:
	    o Initial tugs allocation plan
	• Outputs:
	    o Validated taxi technique for each aircraft
	This choice shall be frozen 1 hour before EOBT to give time for the ground handling organization.

Status	In progress
Rationale	
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-AM01.0001
Title	Aircraft equipment level for tugs allocation
Requirement	Tug allocation modules shall get the information of aircraft level of equipment and taxi technique compatibility:

	• Equipped with e-taxi ability or not • Compatible with tug towing or not
Status	In progress
Rationale	
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	
Category	Interoperability

4.1.3 Tactical 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 for a given aircraft upon request. ATCO should be able to modify the suggested route before validation and the A-SMGCS shall show the environmental impact of the modification
Status	In progress
Rationale	
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0002
Title	A- SMGCS application interactions
Requirement	The radar image should provide feedback for the ATCO: • Environmental impact of the routing modifications • Actual speed or speed tendency of vehicles • Future routes of empty tugs.
Status	In progress
Rationale	
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 centerlines. These shall remain valid under the condition that the underlying speed profiles along the routes are followed accurately by pilots and tug-drivers.
Status	In progress
Rationale	The speed profiles are 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.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-RM01.0002
Title	Calculation of routes
Requirement	ATCOs should be able to influence the default routing / speed profile calculation by adjusting 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.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0004
Title	Modifying routing parameters in the HMI
Requirement	ATCOs should be able to influence the default routing / speed profile calculation by adjusting 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.

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
Requirement	The routing module shall get the following information as basis for the route calculations: • A-CDM data or 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 • runway assignment in the flight schedule has to match the runway mode of operation (RMO, defining active vs. deactive runways) • task assignments of tugs from tug allocation module • vehicle properties of all aircraft and tugs, e.g. length, width/wingspan, distance needed for landing / takeoff, 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) • once a route is (partially) cleared, its cleared path needs to be provided to the routing module

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Status	In progress
Rationale	With that, the routing module is able to provide: • route suggestions • speed profiles • accurate taxi time estimations • engine start-up times as key enabler for the Guidance Service of the A-SMGCS.
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

4.1.3.1 Manage & Execute aircraft taxiing

Identifier	REQ-AEON.01-SPRINTEROP-SM01.0003
Title	A- SMGCS application interface
Requirement	The A-SMGCS radar image shall use the new routing suggestion provided by the routing module. The routing module provides in addition the optimal engines start up time, the ATCO should use it to give the information to the pilot to facilitate the use of engine off technique. The ATCO should also keep the pilot informed of the remaining taxi time. The routing clearances and timing should be given either on R/T or datalink A-SMGCS alerting system is not impacted, clearance conformance can still be checked.

Status	In progress
Rationale	
Category	Interoperability

Identifier	REQ-AEON.01-SPRINTEROP-AC01.0002
Title	Routing for pilots
Requirement	The pilot should 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	
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-RM01.0007
Title	Path re-planning
Requirement	The routing module shall perform path re-planning when the plan execution by pilots 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

Identifier	REQ-AEON.01-SPRINTEROP-AC01.0003
Title	Aircraft engine start support
Requirement	Pilots should 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

4.1.3.2 Manage & execute tugs driving

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0001
Title	Tugs fleet monitoring role
Requirement	A fleet manager should be appointed for any airport that exploits at least XX (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-FM01.0002
Title	Tugs fleet monitoring responsibilities

Requirement	Tugs fleet manager shall be able to monitor tugs allocations to ensure that the allocation plan is going according to schedule. Tug drivers should be aware of their tug allocation schedule so they can anticipate routes throughout the day. Necessary information about tug fleet and tug allocations to monitor current situation and identify 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 needed. The allocation should support fuel saving when possible. Means to cancel planned allocation and to allocate tug to aircrafts should 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-TU01.0001
Title	Tug driving support
Requirement	Tug drivers should 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 should 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-TU01.0002
Title	Human-driven tugs commands takeover support
Requirement	In AEON, tugs will be driven by tug drivers when no aircraft is being towed or pilots when the aircraft is being towed. Driver and pilots should be aware of when they have the control of the tug. In addition, 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	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-TU01.0003
Title	Autonomous tugs commands takeover support
Requirement	In the future, autonomous tugs may be in charge of the complete taxiing operations. The pilot should let the tug manage the routing and focus on the flight preparation. The tug shall then keep the pilot informed on the moment to turn on or off the engines and the progression of the taxiing phase.
Status	In progress
Rationale	Providing information about coupling and uncoupling procedures, and control takeovers will ensure safety and the maximisation of aircraft engine off navigation duration.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0004
Title	Tug driver in charge of taxi operations
Requirement	In case of DTVETS, the responsibility of the taxi phase may remain on the tug driver all along. The aircraft pilot would be able to focus on aircraft processes and checklists.
Status	In progress
Rationale	

Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-FM01.0004
Title	Coordination requests to ATCOs
Requirement	Tugs drivers or Tugs fleet manager shall interrupt the ATCO only when urgent situations require immediate actions. If not, ATCOs should be able to manage requests at their own discretion. Means to send synchronous and asynchronous traffic requests to ATCOs should be provided.
Status	In progress
Rationale	Synchronous communications can interrupt ATCOs performing critical tasks such as managing the ground traffic in peak times. In addition, engaging ATCOs back into tasks on hold is cognitively demanding for ATCOs and may impact ground traffic performance. When possible, stakeholders should communicate asynchronously with ATCOs unless a critical situation requires immediate actions.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-TU01.0005
Title	Coordination requests to tug drivers
Requirement	Tug drivers and pilots must be reachable 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 should 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

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	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

4.2 Safety requirements

In this section, we will consider the most prominent safety events, 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 35, 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 35. Risk assessment matrix

4.2.1 Safety events, hazards, and requirements for tug-enabled aircraft towing

Safety events and hazards for tug-enabled aircraft towing

We divide all safety events and hazards into four categories: mechanical, electric, psychological strain, perception- and organization-related safety events, which are in line with TaxiBot Operational Concept Manual [1].

The most prominent *mechanical safety events* 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 most prominent *electric safety events* 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 events* 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.

[1] Taxibot company, "TaxiBot Operational Concept Manual for Amsterdam Schiphol Airport."

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 events
Category	Safety

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 events
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0003
Title	Safety shoes
Requirement	Tug drivers shall wear safety shoes
Status	In progress
Rationale	
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

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Rationale	Directly related to the identified safety events
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 events
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 events
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 events
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 events
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 events
Category	Safety

Identifier	REQ-AEON.01-SPRINTEROP-ST01.0010
Title	Insulated tools
Requirement	Tug driver shall use insulated tools
Status	In progress
Rationale	Directly related to the identified safety events
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 events

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 events
Category	Safety

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

Identifier	REQ-AEON.01-SPRINTEROP-OR01.0003
Title	Emergency procedures
Requirement	The airport shall develop emergency procedures for tug-enabled taxiing
Status	In progress
Rationale	Directly related to the identified safety events
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 events
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 events
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 events
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 events
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 events
Category	Safety

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

Possible safety scenarios to consider and analyse in AEON project:

- A failed tug blocking a taxiway
- Collision/separation infringement between a towed aircraft and another aircraft/tug on a taxiway, (e.g., as the result of miscommunication/lack of coordination between a tug driver and a pilot in the process of uncoupling during a peak period)

4.3 Performance requirements

Performance requirements drive the process of designing or acquiring a vehicle and generally have to do with capacity, range and/or endurance of the vehicle and combinations or derivatives thereof, such as speed and acceleration. They describe a baseline which allow us to assess the suitability of a vehicle for a certain mission and compare it with alternatives.

For an aircraft towing vehicle, a driving design choice influencing performance is how the vehicle is powered. While a battery powered solution causes no local emissions, need for recharging can reduce the availability the vehicle. While changing batteries might be an option, this is not a trivial task and adds extra cost as well as complexity to the operation. Also charging batteries has implications for the electricity requirements at the airport. Also, while batteries might seem more sustainable, a low utilization might actually make a diesel-powered solution more sustainable from a life cycle cost point of view.

The most important performance requirements deal with the impact on taxiway operations, especially if a new solution causes delay and congestion. The main requirements complying with the refer to the ICAO Global Air Navigation Plan are:

- KPI01 Departure punctuality
- KPI02 Taxi-out additional time
- KPI09 Airport peak capacity
- KPI10 Airport peak throughput
- KPI11 Airport throughput efficiency
- KPI13 Taxi-in additional time
- KPI14 Arrival punctuality
- KPI16 Additional fuel burn

For taxi time, defined here the time it takes between pushback and take-off or landing and arriving at the gate, the most important factor is the distance that need to be travelled which is given by the gate and runway the aircraft has to travel between. Next to this there is a variation for the aircraft type, time of day, weather condition and congestion.

For both towing as well as autonomous e-taxi, the maximum speed the aircraft can move at is an important factor. This speed is mostly defined by the total power available (Joules per second) the combination of aircraft and towing vehicle, or e-taxi device can supply to compensate the drag, mostly dominated by rolling friction drag, times the velocity.

Newton's second law gives us:

$$ma = \frac{P}{V} - D$$

where "m" is the total moving mass, "a" is the acceleration, "P" is the available power, "V" is the velocity and "D" is the drag.

So, when the maximum speed is reached and acceleration is zero, this results in the maximum theoretic speed:

$$V_{\max} = \frac{P_{\max}}{D}$$

At higher speeds, the acceleration is limited by the power available and the drag, as well as the weight.

$$a = \frac{1}{m}\left(\frac{P}{V} - D\right)$$

At lower speeds, traction is the most limiting factor. The traction is a function of the friction coefficient, which is dependent on the tire friction and the surface conditions, and the weight ($W = mg$) on the driven wheels. Similar to the traction, there might also be a force limit for the nose wheel.

$$T_{\max} = \left(\frac{P}{V}\right)_{\max} = \mu W$$

Hence, as drag does not limit our traction, there is a maximum to our acceleration:

$$a_{\max} = \mu_{traction} g$$

Similar to acceleration, the deceleration from lower speeds is mostly limited by traction and the force on the nose gear. Again, here the friction coefficient is the same as for acceleration, however the weight is the total weigh on the wheels used for braking. Here it makes a large difference whether the aircraft assists in braking, as it has the larger mass as well as having only the tow vehicle brake might also lead to stability problems where the mass of the aircraft will cause a rotating moment on the towing vehicle. For emergency braking, this will most likely need to be initiated by the aircraft.

The speed during turn will be limited by the traction on the wheels of the towing, the maximum side force on the nose gear and the cornering stability of the aircraft, which might cause the centre of gravity of the aircraft to tip over the main gear.

Finally, for towing the time needed to attach the vehicle to the aircraft and detach it is important, as it adds to the total tax time and might cause additional congestion, especially near the runways and for aircraft that have just landed and need to be coupled. An important (human) factor here is how effective communication between the tug operator and pilots is.

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0001
Title	Departure punctuality
Requirement	The implementation of the AEON solution should not lead to a significant reduction in departure punctuality by variance in the taxi times
Status	In progress
Rationale	In so far as taxi times are increased, which should be insignificant with respect to the 5-minute scheduling interval, mitigation should be able to take place by earlier pushbacks.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0002
Title	Taxi-out additional time
Requirement	The implementation of the AEON solution should not increase taxi time with such an amount that airlines will need to modify their flight schedules
Status	In progress
Rationale	In so far as taxi times are increased, due to reduced speed and disconnecting the tug, this should be significant compared to the 5-minute scheduling interval.

Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0003
Title	Airport peak capacity
Requirement	The implementation of the AEON solution should not decrease departure runway capacity to below the declared capacity
Status	In progress
Rationale	While issues can cause aircraft to miss their departure slots, this may not lead to a loss of more than a few departure slots per hour.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0004
Title	Airport peak throughput
Requirement	The implementation of the AEON solution should not decrease arrival runway capacity to below the declared capacity
Status	In progress
Rationale	Towing inbound operations may not lead to interference with arrival runway operations and aircraft having to perform missed approaches
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0005
Title	Airport throughput efficiency
Requirement	The implementation of the AEON solution should not increase the aircraft turnaround significantly with respect to the 5-minute schedule interval.
Status	In progress
Rationale	Connecting and disconnecting tugs will add procedures to the operation which should not lead to significant increase in the aircraft spend at the gate.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0006
Title	Taxi-in additional time
Requirement	The implementation of the AEON solution should not increase taxi time with such an amount that airlines will need to modify their flight schedules
Status	In progress
Rationale	In so far as taxi times are increased, due to reduced speed and connecting the tug, this should not be significant compared to the 5-minute scheduling interval.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0007
Title	Arrival punctuality
Requirement	The implementation of the AEON solution should not lead to situations where delays impact arrival punctuality.
Status	In progress
Rationale	There should not be a significant increase in arrival delays above 15 minutes.
Category	Operational

Identifier	REQ-AEON.01-SPRINTEROP-PR01.0008
Title	Additional fuel burn
Requirement	The implementation of the AEON solution shall not lead to increases in fuel burn
Status	In progress
Rationale	Fuel burn should not be higher due to weight penalties during flight or extended running of the Auxiliary power unit
Category	Operational

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. A vehicle that can tow an A321 neo could 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. 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, 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 respective aircraft type with respect 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

4.5 Cost & Benefit

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 the final version of concept of operations as result of the study conducted in the project.

To assess the cost vs. benefit of the system, the time at which different costs and benefits are made play 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, reduces fuel consumption, is during the operation, long term benefits (such as environmental restrictions) might also exist.

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 35, 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 36 There is no daily cost and the benefit is mostly identical for towing identical.

For towing, each extra tow vehicle added to the fleet will lead to an additional number of flight being towed, leading to a marginal savings in fuel consumption, as illustrated in figure 37.

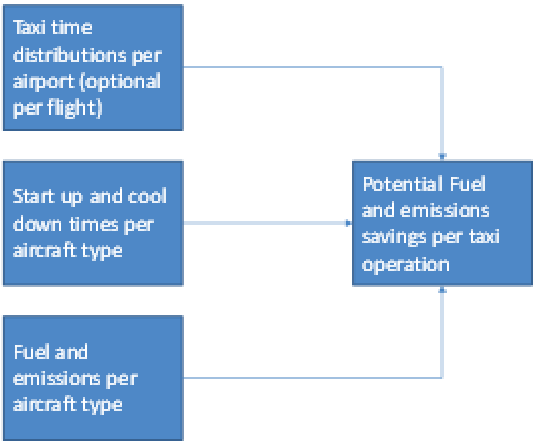

Figure 36: Taxi fuel saving per operation

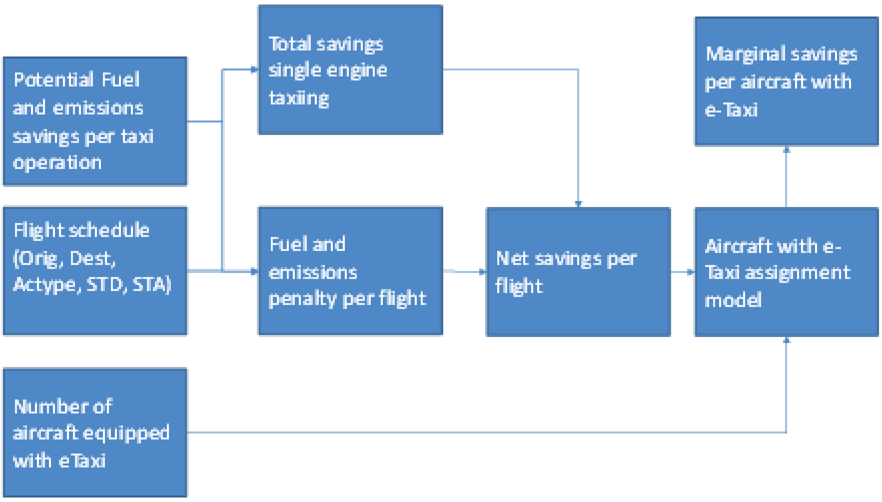

Figure 37: Fuel saving for autonomous e-Taxi

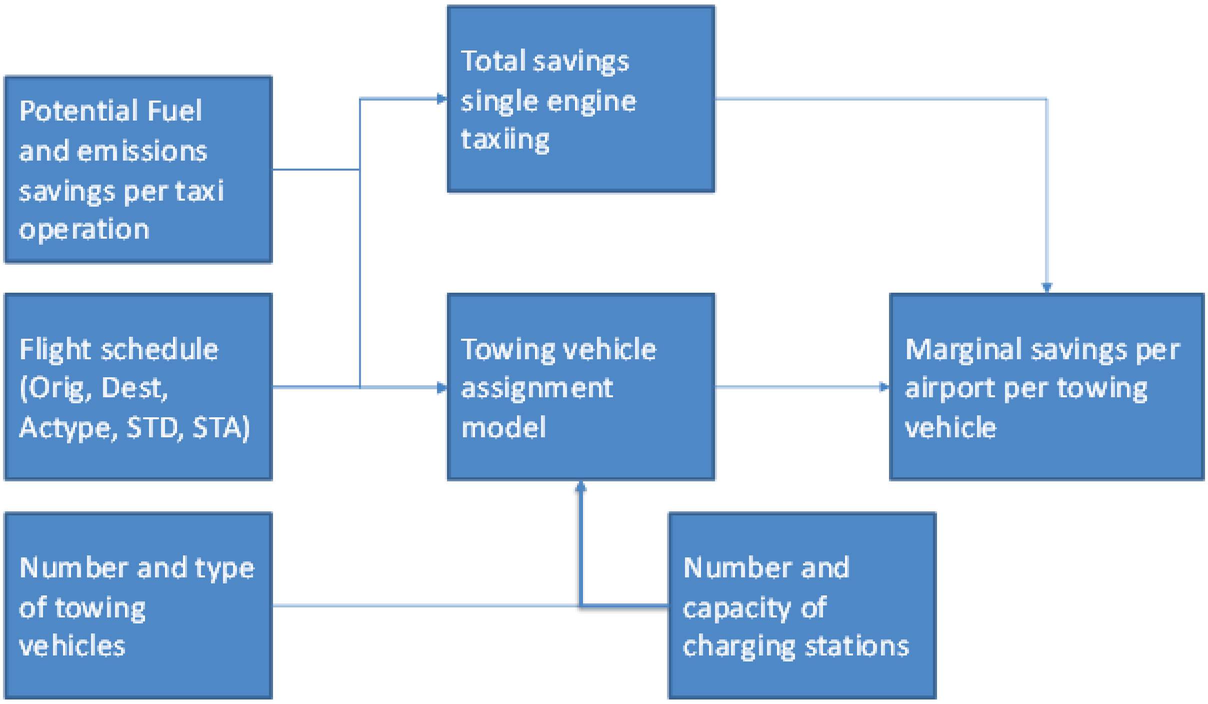

Figure 38: Total and marginal fuel saving for towing

Identifier	REQ-AEON.01-SPRINTEROP-CB01.0001
Title	Cost benefit Tug
Requirement	The total costs of AEON tug solution should be compensated for the total operational benefits
Status	In progress
Rationale	No airport will implement a tug-based system if the costs, mainly fuel savings, cannot be recovered in some way.
Category	Financial

Identifier	REQ-AEON.01-SPRINTEROP-CB01.0002
Title	Cost benefit e-Taxi
Requirement	The total costs of AEON e-Taxi solution should be compensated for the total operational benefits

Status	n progress
Rationale	An airline will only implement an e-Taxi system if the additional costs of the system are outweighed by the operational benefits, primarily fuel consumption.
Category	Financial

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5 References

[1] AEON, D1.3 State of the art

[2] AEON, D3.1 Reference use cases

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

[4] 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

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

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

[7] Taxibot company, "TaxiBot Operational Concept Manual for Amsterdam Schiphol Airport."

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

[9] ICAO Annex 14: Aerodromes, Volume I Aerodrome Design and Operations - 2016

[10] 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

[11] EUROCONTROL Performance Review Report 2019

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