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AEON

ADVANCED ENGINE-OFF NAVIGATION

This assessment report is part of the AEON 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

The AEON project proposes a novel solution to foster the usage of environmentally friendly ground operations techniques such as autonomous (i.e., e-taxi), non-autonomous (i.e., tug vehicles) or Single Engine Taxiing (SET).

The solution proposed was validated using an iterative, participative and multi-layered assessment approach that involved the AEON Consortium and its stakeholders since the earliest phases of the project (D5.1). A three-step iterative validation process was adopted, which included three validation sessions: the initial validation session carried out with selected stakeholders, the intermediate validation session in which the concept was discussed with personnel from Amsterdam Airport Schiphol and Paris Charles De Gaulle Airport, and the final validation session in which the AEON concept and tools were tested in real-time simulation (RTS). During this overall process, the AEON Consortium explored the impact of the proposed solution on several interconnected Key Performance Areas (KPAs), namely: 1) Human Performance, 2) Liability, 3) Safety, 4) Cost-Benefit, 5) Capacity, 6) Efficiency, and 6) Environment.

The present document provides a sub-set of the validation results of the AEON project that focus on the possible impact of the proposed solution on Human Performance (HP) and Liability.

Besides the overall approach, the deliverable includes five main sections. After a brief introduction, section 2 provides an overview of the validation context. Then, sections 3 and 4 concern the HP and Liability assessments and should be intended as complementary. The HP assessment presents the results obtained throughout the initial, intermediate, and final validation. Since the SESAR HP Assessment Process was adopted, the focus of the assessment was on the following aspects: consistency between roles description and the human capabilities or limitations; capability of the system to support human actors in performing their tasks; impact of team communication and team structure on human performance; other transition factors that may or may not support the human actors.

More specifically, the attention converges on the issues experienced by testers performing the role of the TFM and GC/AC. This section further reports a conclusive assessment concerning the confidence in the obtained results.

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The Liability assessment explains the outcomes of the legal analysis of the AEON solution. We applied a heuristic methodology known as the Legal Case. Once properly understood the context and concept from a legal standpoint, this method allows proactively identifying the liability issues, addressing the liability allocation and apportionment considering the findings collected in a multidisciplinary systematic analysis.

Eventually, the report concludes by presenting some joint interdisciplinary conclusions and way forwards. The data obtained and the results of the two assessments allow us to validate the AEON Concept of Operations and will further consolidate it based on the results of the validation activities.

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1 Introduction

1.1 Intended readership

The primary intended audience of this report are the AEON Consortium that will use it to consolidate the AEON CONOPS, and the SJU. However, being a public document, the intended readership also 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 overall aviation community interested in the document.

1.2 Related documents

The document takes into account most of deliverables already produced by the AEON project, with a particular focus on the following ones:

- **D1.1 Initial Concept of Operations**, providing the concept that has been assessed in the validation activities

- **D3.1 Use Cases**, detailing the use cases defined to design the AEON concept and system and partially used also during the validation activities

- **D4.1 and D4.2 presenting the description of the platform** used for the real-time simulation arranged as the final validation session

- **D5.1 Validation Plan**, which describes the overall validation approach of the project and details the specific validation plan formulated for the HP (and liability) assessment

The results included in this report will be used to consolidate the AEON Concept of Operations that will be included in **D1.2 Final concept of operations**.

1.3 Structure of the document

The document is structured in 5 sections:

- Section 1 is the present introduction

- Section 2 provides the context of the validation in which the results presented in this document were produced. In particular, section 2 presents an overview of the validation plan, the validation objectives and success criteria addressed, the use cases taken into account and a description of the data collection methods and techniques used. The final part of the section presents the deviation from the validation plan as defined in D5.1.

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- Section 3 provides the results of the HP assessment, highlighting the results of the different validation activities carried and how they contributed to the gradual definition and evaluation of the AEON concept of operations and tools.
- Section 4 presents the results of the liability assessment, showing the possible liability risks that could be associated to the introduction of the AEON solution and proposing mitigations to be considered already since the next stages of the concept and tool design.
- Section 5 contains conclusions and recommendations, which take into account both the sets of results included in the document.

1.4 Glossary of terms

Term	Definition
Administrative liability	Liability for the violation of an administrative rule or regulation imposed by a competent authority, which leads to a fine or a sanction
Causation	The causal relation/link between cause and effect. Usually, to be proved by the plaintiff
Civil liability	Liability for tort (or breach of contract), that leads to reparation
Criminal liability	Liability for a crime, which leads to detention or fine
Disciplinary Liability	Liability applied by an employer to an employee for the violation of work activities, which may lead to sanctions
E-Taxi	Taxi solution that relies on electric motors that are embedded in landing gear or nose wheel gear in order to allow airplanes to push back and taxi without their jet engines running
Fault	The intentional or negligent failure to maintain a standard of conduct. It may lead to liability if it results in harm to others
Fleet Manager	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.
Levels of automation	The degree to which a task is delegated to a system/technology rather than to humans is referred to as levels of automation (LOA).
Liability	Being subject to a sanction for harm or damages
Negligence	Carelessness amounting to the breach of a duty (failure to do something) that may lead to damage for others

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Product Liability	Legal liability of manufacturers and others for defective products. In the EU the producer of a defective product that causes death or personal injury/damage to property is strictly liable.
Responsibility	Having the duty to perform or execute a task: being accountable (see task-responsibility)
Single Engine Taxi	Taxi solution that involves the use of only half the number of engines installed to generate the energy needed for taxiing
Strict Liability	Legal liability imposed on the causation of a harm, regardless of fault
Task-Responsibility	Agents are task-responsible for a certain outcome when they have the duty and the capacity to ensure such outcome, given their role.
TaxiBot / tug vehicle	Dispatch towing vehicle and 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.
Vicarious Liability	Legal liability imposed on a person for the tort or crime committed by an employee or agent

Table 1: Glossary of terms

1.5 Acronyms

Term	Definition
AB	Advisory Board
AC	Apron Controller
ACC	Area Control Centre
A-CDM	Airport Collaborative Decision Making
AEON	Advanced Engine Off Navigation
AMAN	Arrival Manager
AMS	Amsterdam Airport Schiphol (IATA code)
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
APOC	Airport Operations Center
APTO	Airport Operator

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A-SMGCS	Airport Surface Management Ground Control System
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSP	Air Traffic Service Provider
CBA	Cost Benefit Analysis
CDG	Paris Charles De Gaulle Airport (IATA Code)
CONOPS	Concept of Operations
DET	Double Engine Taxi
DMAN	Departure Manager
DSNA	France Civil Aviation Authority
EFB	Electronic Flight Bag
EHAM	Amsterdam Airport Schiphol (ICAO code)
E-OCVM	European Operational Concept Validation Methodology
FC	Flight Crew
FM	Fleet Manager
FO	First Officer
GC	Ground Controller
GH	Ground Handler
HMI	Human Machine Interface
HP	Human Performance
KPA	Key Performance Area
KPI	Key Performance Indicator
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
LFPG	Paris Charles De Gaulle Airport (ICAO Code)
LOAT	Level of Automation Taxonomy

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LTO	Landing and Take-Off cycle
NM	Network Management
OSED	Operational Service and Environment Definition
PIC	Pilot In Command
RTS	Real-Time Simulation
SAS	Situation Awareness Questionnaire
SESAR	Single European Sky ATM Research Programme
SET	Single Engine Taxi
SUS	System Usability Questionnaire
TD	Tug Driver
TFM	Tug Fleet Manager
TOBT	Target Off Block Time
TRL	Technology Readiness Level
TSAT	Target Start-Up Approval Time
UC	Use Case
VA	Validation Assumption
WP	Work Package

Table 2: Acronyms and terminology

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2 Context of the Validation

The main aim of AEON is to foster the usage of environmentally friendly ground operations techniques such as electric towing vehicles, electric taxi systems or single engine taxiing. To this end, the project Consortium was intended to provide a viable solution that integrates the three taxiing technologies into an innovative concept of operations that reduces emissions produced in surface movements, while keeping relatively high airport capacity.

The validation activities were pivotal for the development of the AEON CONOPS as they allowed the Consortium to analyse the adequacy of its application in the aviation system and to use the results of the validation sessions to refine the design of the concept and the associated tools.

The validation process adopted entails a user-centred design and evaluation approach and foresees an iterative 3-step validation phases (see section 2.3). The evaluation process focuses on several aspects of the operational concept, considering, in particular, the impact of the AEON solution on a set of Key Performance Areas (KPAs) such as the environment, as well as human performance, safety, liability, capacity, efficiency, and cost-benefits for the aviation stakeholders involved.

Note that this section presents a comprehensive overview of the AEON CONOPS and of the overall validation plan adopted in the project. This is pivotal to provide the context of the validation. Nevertheless, the assessments reported in sections 3 and 4 focus just on two of the KPAs addressed by the project (i.e., HP and Liability) while the results related to the other KPAs are provided in other deliverables (i.e., D5.3 Safety Assessment Report and D5.4 Cost assessment report).

The insights and recommendations proposed by this document were subject to an open discussion with the Advisory Board during a dedicated meeting. The inputs provided on that occasion were analysed and are an integrant part of the results presented here.

2.1 Summary of the AEON CONOPS

2.1.1 Purpose and usage of the AEON solution

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

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

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In light of the above, the AEON solution is planned to influence ground operations at different time phases of the planning, and to involve a variety of different operators both in the long/medium-term planning and execution phases of the procedures[1].

In the long-term planning phase, the airport layouts and airlines taxi preferences are provided through the A-CDM to the fleet management algorithm. The AEON fleet management algorithm helps estimate the adequate number of tugs to operate a given airport in a given period, considering its specific traffic. The tool further supports the TFM to identify the taxiing technique allocated to each aircraft. Taking into account the arrival and departure sequences (from AMAN and DMAN), plus the operational constraints of the tugs fleet, the AEON fleet management algorithm sizes the fleet of tugs needed and eventually allowing the relocation during tactical operations. For example, we could envision a situation in which all the flights are suggested to be towed by a tug, instead of using electric engine or single engine taxiing techniques, as this strategy emerges as the most effective one in the specific case and the number of available tugs is consistent with the request. Conversely, there could also be situations in which the available tugs are not sufficient and there is a need for specific flights to use electric engine or single engine techniques, depending also on the technical equipment they have.

In the medium-term planning phase, the proposed allocation of taxiing techniques to aircraft is provided to airlines and ground handlers by means of the Airport Collaborative Decision Making (A-CDM) portal. Airlines and ground handlers have until one hour before the Target Start-Up Approval Time (TSAT) of each flight to accept the proposal or change the allocation in order to accommodate last minute operational events, requests or needs. One hour before departing/arrival time, the decision is frozen, and the execution phase starts.

During the execution phase, a second AEON algorithm, called AEON multi-agent system for path planning, provides a support for ATC officers and pilots to manage the actual taxiing, thanks to dedicated HMIs.

By interfacing with the Advanced Surface Movement Guidance and Control System (A-SMGCS) HMIs, the AEON algorithms – respectively, the fleet manager algorithm for tug allocation and multi agent system for path planning – help:

- the tug fleet manager (TFM)[2] to reassign tugs when unforeseen operational events imply a change in the initial plan.
- the ground and apron ATCOs: i) to identify the taxiing technique allocated to each aircraft, ii) to define the taxi clearances, especially for towed departing aircraft that need to stop for detaching process somewhere without disturbing the rest of traffic. In addition, it provides

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[1] Please notice that the terminology has been changed with respect to the one used in previous deliverables of the project in order for an higher consistency with the SESAR terminology. As such, long/medium-term planning phase are consistent with the strategical and tactical phase envisioned in the Concept of Operation Initial Version [2]. The executive phase regards the stage in which the TFM and Ground ATCO perform the tasks previously defined and adapt the plans to real time limitations.

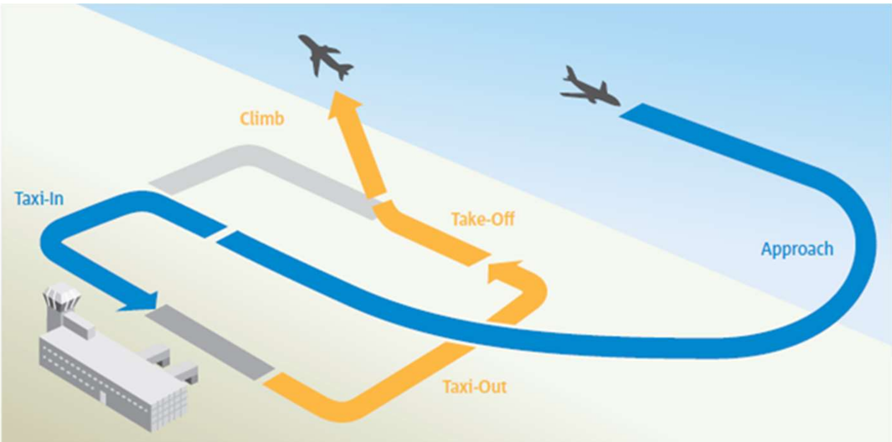
[2] a new role introduced together with the AEON solution

real-time updates on remaining taxi time to pilots in order to facilitate engines start-up procedure.

In addition, the AEON solution considers that the aircraft using electrical engines for taxiing (or towed by hybrid tugs) are more easily controlled on speed and can take speed targets 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. The AEON solution could thus provide speed targets to avoid aircraft arriving simultaneously to the same intersection, hence smoothing traffic control. However, considering that this new type of ATC clearances could create additional workload and radio frequency usage, the AEON consortium explored the possibility to give speed cues to the pilot through a datalink, to be displayed on the electronic flight bag (EFB).

2.1.2 Operational environment

The operational environment described in the OSED of the AEON solution is associated with all kinds of ground operations in the airport environments, from high to low complexity. Applying such a concept to low complexity airport environments implies a significant simplification and it should lead to potential new solutions. In particular, autonomous taxiing solutions may fit smaller airports better than non-autonomous solutions. In such airports, the taxi time is short enough not to be impacted by the lower speed of the e-taxi systems, while the benefit of non-autonomous solutions would be limited. However, as described in the Solution Assessment Plan [1], more emphasis was put on airports characterised by complex ground operations.



LTO cycle

Mode	Thrust	Time
Take-off	100%	0.7 min
Climb	85%	2.2 min
Approach	30%	4.0 min
Taxi	7%	26 min

Figure 1. Landing Take-Off Cycle [2]

In such a 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.

The operational characteristics of the solutions proposed may 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 objectives. The services are either provided by the Airport Operator (APTO) or by the Aircraft Operator / Ground Handler (AO/GH).

In addition, the operative methodology can be pre-selected using HMI-enabled tools integrated into existing A-CDM platforms. In addition to other benefits, the operational characteristics offer aviation stakeholders flexibility and optimization of the fleet. The provided concept of operations can be used for both independent and hybrid modes of operations.

The current operations do not offer complete engine off techniques that are integrated into an HMI interface platform.

2.1.3 Roles and responsibilities

The AEON solution is expected to affect the roles and responsibilities of most of the actors involved in day-to-day ground operations of the airport. The following list provides the roles involved, while more details about the expected impacts are proposed in sections 3.3.2. Please, notice that, at this stage of the concept development, the Network Management (NM) is not considered impacted as 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.

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

- Airport Operator (APTO) is intended as a natural or legal person engaged in or offering to engage in an airport operation. In AEON these subjects are required to take part in the long/medium-term planning phase accepting or suggesting the most profitable taxiing techniques.
- Airlines / Aircraft Operators (AOs) are intended as natural or legal persons engaged in or offering to engage in air service. In AEON these subjects are required to take part in the long/medium-term planning phase accepting or suggesting the most profitable taxiing techniques.
- Air Navigation Service Providers (ANSPs) and Air Traffic Service Providers (ATSPs) generally include the services provided by Air Traffic Controllers (ATCOs) working at airports for the arrival and the departure flight phases and in Air Traffic Control Centres (ACCs) for the en-route flight phase. In AEON, the most impacted subjects should be airport ATCOs and, more specifically, the Apron Controller (AC) and the Ground Controller (GC). Indeed, these latter shall coordinate their activities with the ones performed by the Tug Fleet Manager (TFM) and supervise the taxiing operations according to the suggestions provided by the AEON system.
- Tug Fleet Manager (TFM)is a new actor introduced by the AEON CONOPS. This latter is intended to support ATCOs in the safe and fair management of taxiing operations. This subject is basically devoted to the efficient allocation and safe dispatching of tugs according to the traffic conditions of the airport.
- Tug Driver (TD) is a ground handler specialised in carrying towing vehicles. Usually, this subject has specific duties during pushback manoeuvring. In the AEON solution, s/he gives control to the pilot in command after performing pushback and only drives on the taxiways when the tug

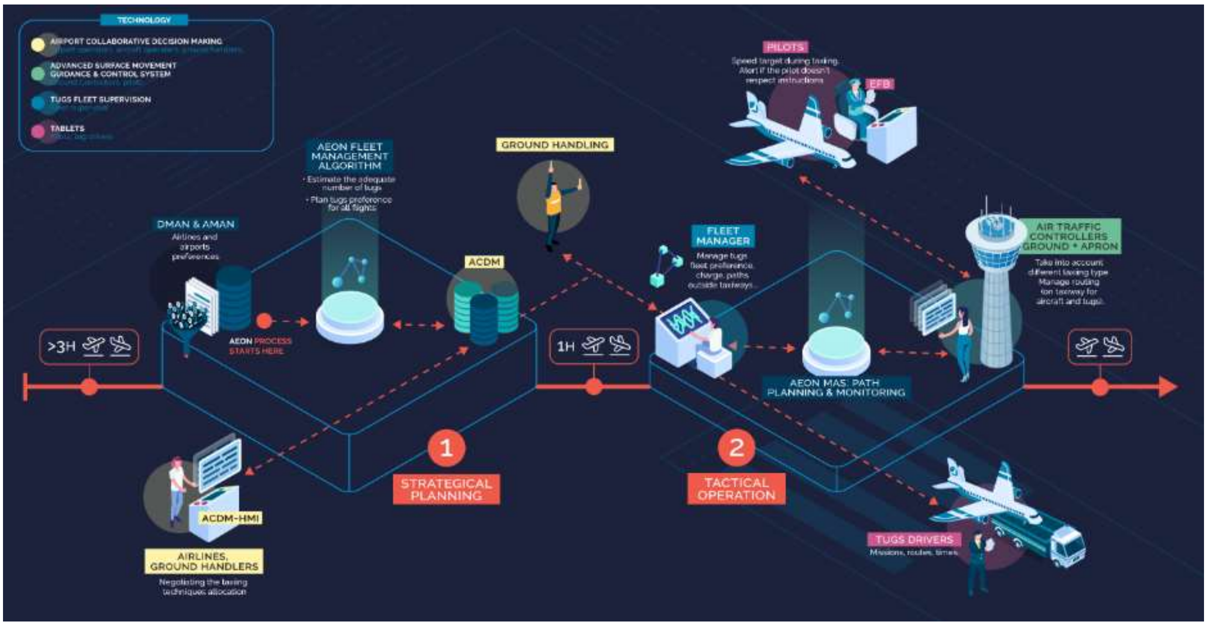


Figure 2: Visual representation of the AEON concept of operations, including the involved actors.

is not coupled (*i.e.,* empty), according to the instructions respectively provided by the AC and GC. Furtherly, s/he interacts with the TFM that provided instructions for new missions.

- Flight Crew (FC) is intended as the personnel responsible for the operation of an aircraft during the flight. The two main actors are the Pilot in Command (PIC) and First Officer (FO). With AEON, they are supplied with information about taxiing operations, specifying the taxiing technique adopted for the flight and the associated taxiways operations.

The following picture shows a visual representation of the AEON concept of operation, in which all the concerned actors are included.

2.1.4 Impact on already existing systems and tools

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

a) the Airport Collaborative Decision-Making application (A-CDM), since the taxiing techniques are impacting the taxi time and procedures, and

b) the Advanced Surface Movement Guidance and Control System (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 tugs, would also imply additional vehicles to be managed, so that a new role of TFM, supported by dedicated tools and HMIs, has been introduced.

2.1.5 Possible impacts on operations

The variety of engine-off taxiing techniques envisioned by the AEON project may impact current taxi operations from the long/medium-term planning of the operations to the way traffic is managed on taxiways and how aircraft navigate through airport locations. For instance, the maximum speed limit of electric taxi technologies may impact the airport ground traffic flow. Also, the integration of more tugs for towing aircraft on taxiways may intensify the already dense traffic, thus impacting controllers' and pilots' activities.

To cope with these changes, AEON offers support for sizing the fleet of tugs and allocating them to specific aircraft as well as for suggesting other engine-off techniques to be used by the rest of the traffic that for a variety of different reasons may not benefit by the towing service. AEON also supports planning optimal ground traffic, through novel algorithms that suggest the best taxi trajectories for each vehicle (aircraft and tug) on the airport taxiways. Additionally, AEON provides a set of interactive tools that supports airline companies, airport service companies, airport ground controllers, tug fleet managers and pilots to perform airport taxi-related tasks, as well as the collaboration between stakeholders to optimise airport ground operations workflow.

In this section, we describe the possible impacts of the AEON solution on existing ground operations at three different phases: long- and medium-term planning phases, and executional. In the long-term planning phase, we consider the strategic estimate of the adequate number of tugs to operate a given airport in a given period, considering its specific traffic; in the medium-long term planning phase the proposed allocation of taxiing techniques to aircraft is provided to airlines and ground handlers. They can accept/change/refuse the allocation up to one hour in advance to landing and/or departing time. Then, in the execution phase, we address the operations performed by TFM, ATC officers and pilots to manage the actual taxiing.

2.1.5.1 Possible impacts during the long/medium planning phase

In AEON, the introduction of tugs for taxiing operations aims to create a new service at the airport, in addition to the existing ones. Considering the various economic models that may be used for implementing AEON, for the sake of clarity, we can distinguish two different categories of subjects.

The first category concerns the suppliers of tug service. These may be the Airport Operator (APTO) or other companies able to offer the facilities at issue. Basically, these operators have to size their fleet of vehicles according to their goals in terms of ecological, economic or operation performances. Owning the fleet, these subjects should also have supervisory duties on the appropriateness, efficiency, and maintenance of the vehicles offered. They thus should have all the corollary duties to collaborate with the other ground handling services required to ensure an adequate level of safety and efficiency of their vehicles (e.g., fuel and oil handling, maintenance handling – generally, see: Directive 96/67/EC).

The second category involves the intended recipients of towing services, namely the airlines and other aircraft operators. These latter should book the tug service for their aircraft, and this may impact their ground handling strategies and airport resource management. Since tugs might be limited in number, even more during peak traffic, airlines are required to indicate the taxi capabilities of their aircrafts and their taxi preferences as alternatives.

Between these two categories, there is the role of the tug fleet manager (TFM). This figure is a novelty introduced by the AEON CONOPS to ensure the best availability of the vehicles fleet by monitoring their status, allocating them to aircraft and planning maintenance operations. The role of this actor may be affected by the economic model adopted for the implementation of AEON and the legal qualification of this subject within the airport organization. On the following page, the dedicated section will provide more details about this actor.

2.1.5.2 Possible impacts during the execution phase

Engine-off technologies introduced in AEON prospectively change aircraft's speed profiles on taxiways and introduce additional vehicles on taxiways and service roads. This may have significant impacts on taxiing procedures and the way stakeholders operate.

At present, aircrafts already have disparate speed profiles and manoeuvrability levels. However, the introduction of the AEON solution may have additional effects on this variability, impacting airport schedules and requiring more time to reach a given location of the airport using such taxi technologies. As a consequence, airlines and APTO may have to re-plan ground handling strategies to cope with longer taxiing time.

Since aircraft may be able to taxi engine-off, the AEON solution supports pilots planning engine start time and location to optimise fuel consumption. In doing so, the software furtherly takes into account engine start-up procedures defined by airline companies and airports, avoiding any timeout. The system can provide a similar operative support even during towing to or from runways, when pilots have to incorporate attaching/detaching time and location with the tug before departure or after landing. Finally, every aircraft is required to follow speed recommendations to optimise the traffic flow and fuel consumption. Therefore, pilots have to monitor and control the speed of aircraft accordingly.

The hypothesis underlying to the AEON solution implies that tugs use the taxiways. This may increase the work demand for routing and communication between ATCOs and taxiway users. Like aircraft, taxi clearances and routes are needed for tug drivers to navigate throughout the airport. This could increase ATCOs' workload and intensify the verbal communications. The heterogeneity of vehicle characteristics on taxiways may create conflicts which need stakeholders' collaborative efforts to resolve.

In light of the above, at execution level, the tug fleet manager is responsible for proposing an allocation plan to provide tugs on time for towing operations to be performed as requested. In particular, supported by the AEON algorithms and tools, the TFM has to assign the towing vehicles to aircraft according to technical requirements and companies' preferences. The fleet manager also ensures the tugs usage optimization by dispatching any available tug at any time if required. Available tugs may be dispatched to resolve taxiways traffic congestion at the fleet manager's discretion.

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2.2 Summary of the AEON Validation Plan

2.2.1 Overall Validation Plan Description and Purpose

The AEON project adopted an iterative validation approach. As described in the Validation Plan (D5.1), a 3-step validation process was designed and used in order to progressively validate the concept of operations during its development, throughout the entire project duration. In particular, three sets of validation activities were organised in different phases of the project, to which different objects, aims, levels of analysis and methods were associated.

The preliminary evaluation session was carried out in September 2021, during the 1st Advisory Board Meeting of the project. The purpose of the preliminary validation session was to involve the main stakeholders of the AEON concept in a common session of user needs collection and to get their feedback on the very first version of the concept of operations. The inputs collected were then used to refine the initial version of the AEON concept of operations, that was reported in D1.1. Information about the organisation and the results of the preliminary validation activity is provided in Chapter 3.1.

The intermediate evaluation session was carried out in the period between February and June 2022 and consisted in a series of feedback collection sessions organised at the airports of Paris Charles De Gaulle (CDG - LFPG) and Amsterdam Airport Schiphol (AMS – EHAM). During this validation phase, selected use cases were demonstrated to the participants using the prototypes developed by the project. These sessions offered the opportunity to collect feedback both on the operational concept (that in the meantime had been more detailed with respect to the initial version included in D1.1) and on the prototypes. The personnel involved was from different organisations and represented a rich set of stakeholders (i.e., ATCOs, ANSPs, airport management, pilots, airlines). The results collected in this phase were then used to further consolidate the concept of operations and the prototypes to be validated in the final validation session. Information about the organisation and the results of the intermediate validation session is provided in Chapter 3.2.

The final evaluation session was carried out in July 2022 at ENAC and consisted in a human-in-the-loop real-time simulation (RTS) in which ground air traffic controllers (GCs / ATCOs) from DSNA managed realistic traffic samples using the concept of operation and the prototypes developed by the AEON project. The operational scenario used during the RTS referred to the Paris CDG airport. Pseudo pilots and pseudo tug drivers were also involved in order to ensure a certain degree of realism. The RTS lasted 3 working days and involved 8 ATCOs, who were alternatively requested to play the role of ground controllers and to work as TFM. The results of this validation session will be used to further consolidate the AEON CONOPS, whose final version will be reported in D1.2. Information about the organisation and the results of the final validation session is provided in Chapter 3.3.

2.2.1.1 The scope of the validation activities

As explained, the AEON solution postulates the introduction of decision-making support software for the integrated management of different engine-off taxiing techniques. Different interfaces, as well as dedicated algorithms, were developed for the many ground operators involved. The following assessments thus focused on the prospective operative functioning of a set of dedicated tools. Note that these support operators in choosing the best use of the different available taxiing techniques for each flight and then managing potential operational events that would prevent the correct execution of the initial plan.

Approaching the technical analyses of the solution is essential to bear in mind a paramount warning. AEON considers three techniques to perform engine-off taxi. However, these methods are not the core of the project, which instead covers the necessary tools to facilitate multi-agent decision-making about the choice of these alternatives. This premise has crucial implications for HP and liability assessment.

On the one hand, from a scientific and methodological standpoint, it is essential to highlight how the assessment activities focused on the use of the tools and not directly on the operative scenarios postulated by the single taxi techniques considered. On the other hand, the HP and liability analyses included within their scope of inquiry the direct consequences related to the use of AEON tools on current operations, and this led to consider in greater detail some techniques instead of others. Note that this effect is an outcome of the outline of the tools, not a limitation of the assessments here at issue.

Against this background, from an operative perspective, Single Engine Taxi (SET) and E-Taxi techniques do not significantly differ from the traditional Double Engine Taxi (DET) procedures. From an angle, in the case of SET, the actors involved only need to adapt the previous standards and protocols to the single-engine technique. Once available embedded E-Taxi solutions, instead, the main differences will concern the technical features of the aircraft. These differences, however, should have a limited impact on the interactions of the actors involved due to the use of optimised path planning and speed cues. In this case, the pilot will remain the subject in charge of the material execution of the taxi: s/he will need the due training and licence extensions and will be accountable for the safe performances of the e-taxi-powered ground movements. On the contrary, the introduction of towing techniques involves a considerable increase in the number of vehicles running on taxiways. The safe and efficient use of these vehicles implicitly requests the redefinition of the procedures previously in force and, when needed, the introduction of new ones. Consequently, this reviewing process imposes a redefinition of roles and figures and, consequently, of their related task responsibilities. On these grounds, the legal analysis of the AEON solution will pay attention on the effects of the operative procedures required for the safe and efficient allocation and dispatching of these vehicles.

In light of this, the most evident novelty concerns the position of the TFM, the actor devolved to the safe and efficient management and allocation of tug vehicles. More specifically, the legal outline of this subject needs to be carefully analysed according to her/his new specific tasks. Consequently, the operative and legal regime of the other actors asked to collaborate with her/him needs to be reconsidered.

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2.2.2 KPAs and High-Level Validation Objectives

A common set of key performance areas (KPAs) and high-level validation objectives was defined for the project, to be addressed in different ways during the three validation sessions above mentioned.

KPAs	High-Level Validation Objectives	Val. sessions
Human Performance	To validate that the AEON concept does not negatively impact the required Human performance levels	Initial Intermediate Final
Safety	To investigate the impact that the AEON concept is supposed to have in terms of safety and identify main initial issues	Initial Intermediate Final
Cost-benefit	To validate that the AEON concept enables a sustainable cost-benefit balancing for autonomous / non-autonomous electric taxiing systems	Final
Capacity	To determine the influence that the CONOPS might have on airport capacity	Final
Efficiency	To investigate that the AEON concept enables a suitable exploitation of airport capacity	Intermediate Final
Environmental impact	To investigate whether the AEON concept has positive effects on the environmental impact of taxiing operations	Final
Liability	To determine that the AEON Solution does not introduce unacceptable liability risks for actors and stakeholders	Final

Table 3. KPAs and high-level validation objectives investigated by the project

2.2.2.1 Validation objectives of the HP assessment

According to the E-OCVM validation objectives generation process [4], the HP high-level validation objective above mentioned was then decomposed into lower-level validation objectives and criteria that guided the final evaluation session. The SESAR HP assessment process [5] was used as reference and guidance for the definition of the detailed validation objectives and criteria associated to the HP assessment (VO1).

The result of this work is summarised in the following table, that was used to guide to HP assessment during the entire project, particularly during the organisation, execution and the reporting of the intermediate validation session and the final validation session.

Validation objective	Detailed validation objective	Criteria
VO1 | HUMAN PERFORMANCE		
To validate that the AEON CONOPS does not negatively impact the required HP levels	1 The role of the human is consistent with human capabilities and limitations	1.1 Roles and responsibilities of human actors are clear and exhaustive
		1.2 Operating methods are exhaustive and support human performance
		1.3 Human actors can achieve their tasks
	2 Technical systems support the human actors in performing their tasks	2.1 Appropriate allocation of tasks between the human and machine
		2.2 The performance of the technical system supports the human in carrying out their task
		2.3 The design of the human-machine interface supports the human in carrying out their tasks
	3 Team structures and team communication support the human actors in performing their tasks	3.1 Effects on team composition are identified
		3.2 The allocation of tasks between human actors supports human performance
		3.3 The communication between team members supports human performance
	4 Human Performance related transition factors are considered	4.1 The proposed solution is acceptable to affected human actors
		4.2 Changes in competence requirements are analysed
		4.3 Changes in staffing requirements and staffing levels are identified

Table 4. HP Validation Objectives

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2.2.2.2 Validation objectives for the liability assessment

The high-level validation objective associated to the Liability KPA was also further detailed into lower-level validation objectives in order to structure the assessment and the awaited results. The list of low-level validation objectives associated to liability is provided in the following table. They follow the Legal case approach adopted in the project for the liability assessment and were used to guide to liability analysis during the project.

Validation objective	Detailed validation objective	Criteria
VO7 | LIABILITY		
To validate that the liability risks associated to the AEON solution are acceptable for actors and stakeholders	1 The AEON solution is compliant with current regulatory framework	1.1 The AEON solution is compliant with current regulatory framework
	2 Liability risks are acceptable for the concerned actors and stakeholders	2.1 Liability risks for operators are considered
		2.2 Liability risks for organisations are considered
		2.3 Liability risks for manufacturers are considered
	3 Liability risks mitigations are considered	3.1 Means to mitigate the liability risks of the operators are considered (if needed)
		3.2 Means to mitigate the liability risks of the organisation are considered (if needed)
		3.3 Means to mitigate the liability risks of the manufacturers are considered (if needed)

Table 5. Liability Validation Objectives

2.2.3 Reference operational scenarios

The reference operational scenarios used for the validation activities referred to Amsterdam Airport Schiphol (AMS) and Paris Charles De Gaulle (CDG) airports. Both of them were used as reference in the feedback collection sessions organised with operational personnel, experts and key stakeholders during the initial and the intermediate validation phases. Differently, the RTS organised in the final validation session reproduced exclusively the operational scenario of Paris Charles De Gaulle (CDG), using ground traffic data from the peak season on the 1st of September 2019.

2.2.4 Summary of Validation Use Cases

A selection of representative use cases from the AEON deliverable D3.1 [6] were used to present the concept of operations and get feedback from operational personnel, experts and key stakeholders during the initial and the intermediate validation phases. A subset of these uses was also selected to be implemented during the RTS organised for the final validation phase. In particular, in order to ensure that the different aspects of the AEON new operational concepts are well integrated together, the relevant use cases were associated with a high implementation priority.

As anticipated and explained in other deliverables, the AEON concept maturity is relatively low. This induced the Consortium to gradually approach the different operative scenarios and formulate the validation required uses-cases according to a modular method. The methodology used to undertake this study and the related technical assessments included the results and the scenarios gradually elaborated over the AEON progresses. In the preliminary evaluation the attention of the AB mainly converged on the use cases sketched out in the initial version of the CONOPS (D1.1). The intermediated and final validations relied on the more solid scenarios presented as representative use cases (D3.1). This is the reason why the levels of detail of the outlines progressively increased over the project, allowing more tailored considerations.

Consistently to the set of use cases identified in the D1.1 and D3.1, this report analyses the human performance and liability issues taking as references a series of different and concurrent objectives of the AEON solution.

In particular, considering the strategic long-term planning phase, the attention focuses on the estimate of the adequate number of tugs to operate a given airport, while in the medium-term planning phase, the focus switch to efficient use and allocation of tugs available according to the suggestions provided by the AEON system. These tasks were briefly outlined in D3.1, defining the use case SP1. This latter concerns "Decision support for sizing the tugs fleet” and considers a situation where all aircraft need to be towed. The expected results on operations are an optimal sizing of the tugs fleet done at the strategic long/medium-term level. Accordingly, the APTO or tug service provider will have to consider the identified number of tugs to size their fleet and use allocation plans to estimate possible impacts on operations.

On the other hand, looking at the execution phase, the attention focuses on the efficient use and allocation of tugs available according to the suggestions provided by the AEON system. The validation scenarios were outlined in D3.1, considering two use case blocks. On the one side, sample situations concerning the efficient use and allocation of tugs available are addressed in the use cases SP1, TP1, TO2 and TO3. These examples are respectively devoted to the optimal sizing of the tugs fleet according to traffic conditions (SP1), the allocation of tugs to aircrafts during a given term (TP1), tug dispatching (TO2), and the management of multiple engine-off taxiing techniques according to the given traffic conditions (TO3). On the other side, the second set of samples provided significant insights relying on the use cases addressing the reallocation issues related to already assigned tugs due to operational contingencies (D3.1, uses cases TP2, TP3, and TO6). Specifically, the aspects mainly considered include the difficulties that would be expected in updating an already assigned taxiing technique (TP2), updating the allocation due to a runway reconfiguration (TP3), and dispatching a tug to a departure delayed aircraft (TO6). Note that the mentioned use-cases served as a basis for the final validation tests, but some had to be adapted to accommodate validation necessities and context limitations. The elements here reported were considered but eventually adapted to the validation necessities and the context limitations.

The table below systematically presents the scenarios used for the validation activities and highlights the use-cases considered for their formulation. This summary aims to track the evolution and establish

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a true picture of validation scenarios, putting emphasis on the parallelism between the contents proposed in D3.1 and D5.1.

	Use cases [D1.1 and D3.1]	Validated scenarios [D5.1]
Preliminary Evaluation **[D1.1]**	1) Change of use of alternate taxing method 2) AD-HOC delay due to missing passenger/ delay in aircraft (TOBT delay) and 3) Regulated (CTOT Allocation).	The different aspects composing the AEON initial operational concept (i.e., the multi-agent system for routing, the algorithm for fleet management, the Human-Machine Interaction and preliminary use cases) and how their integration could bring an added value in future airport operations. Towing vehicles supervision tool, routing suggestion and automated control of vehicles, ATCOs and pilots/drivers HMI to support speed cues for smoother traffic
Intermediate Evaluation **[D3.1]**	TO1 "Three departures with Engine-off taxiing techniques" TO2 "Tug dispatching" TO3 "Medium traffic with multiple engine-off taxiing techniques"	The different aspects composing the AEON initial operational concept (i.e., the multi-agent system for routing, the algorithm for fleet management, the Human-Machine Interaction and preliminary use cases) and how their integration could bring an added value in future airport operations. Explore the design of the A-SMGCS to support ATCOs understanding the taxiing operations.
Final Evaluation **[D3.1]**	SP1 "Decision support for sizing the tugs fleet" TP1 "Tug allocation to aircraft during the day of operation" TP2 "Updating an already assigned taxiing technique" TO1 "Three departures with Engine-off taxiing techniques"	Considering the long/medium term planning phase, the attention focuses on the efficient use and allocation of tugs available according to the suggestions provided by the AEON system. Looking at the executive phase, the attention focuses on the efficient use and allocation of tugs available according to the suggestions provided by the AEON system,

	TO2 "Tug dispatching" TO3 "Medium traffic with multiple engine-off taxiing techniques" TO6 "Dispatching tug to a departure delayed aircraft"	dispatching tugs and updating assigned taxiing techniques in case of delays. The reference scenario played in the Final Evaluation was using a ground traffic situation from Roissy – CdG airport with ground traffic data from the peak season on the 1st of September 2019.

Table 6. Summary of Validation Use Cases and Scenarios

2.2.5 Validation Assumptions

The following list of validation assumptions (VA) and limitations was identified, together with associated mitigations. The assumption and limitations identified were considered compatible with the low level of maturity of the AEON Concept of Operations and tool validated.

Assumptions / Limitation		Mitigations
VA1	The results are mostly qualitative and based on experts' feedback	At this stage of research project this validation assumption was not considered a limitation. Rather it was considered acceptable and thus was not mitigated.
VA2	The evaluation sessions are not fully realistic and in many cases mock-ups and/or videos are used with the participants, particularly during the intermediate validation session.	At this stage of research project this validation assumption was not considered a limitation. Rather it was considered acceptable and thus was not mitigated.
VA3	The role of TFM requires ATC competences and thus is played by an ATCO.	ATCOs were requested to cover the TFM role. We were aware that this choice could have been considered reductive by the ATCOs. However, we decided to use the validation session to study if this solution could be feasible/acceptable and to explore the existence of valid alternatives.
VA4	Empty tugs use the taxiways rather than dedicated service roads.	This is the main constraint adopted by the project consortium, and we were aware that it had the potential of largely affecting the human performances and safety of the concerned actors. The alternative, represented by the use of service roads, was not mature enough to be used. Thus, we accepted the constraint and, aware of the validation limitation possibly associated to this choice, used the

		validation sessions to explore the acceptability of this solutions, and how to implement the alternatives.

Table 7. Validation assumptions

2.3 Data collection methods

A large set of data collection methods was used to validate the AEON Concept of Operations and the associated tools in the different validation sessions.

Validation sessions	Data collection methods
Initial	Focus group
Intermediate	Focus group
Final	Over-the-shoulder observation Post-run debriefing Post-run questionnaires • Bedford to assess the impact of AEON on the workload of ATCO and FM • SART to assess their situational awareness • SUS to assess their opinion on platform usability General final questionnaire Data-logs (limited set)

Table 8. Data collection methods

2.4 Deviations from the Validation Plan

The validation activities were preprepared and executed as described in the AEON Validation Plan (D5.1) and no deviations are to be reported in the way the study was carried out.

Nevertheless, a major deviation is worth being reported concerning the algorithms for tug allocation and path planning used during the final validation session. Unfortunately, due to technical issues emerged during the preparation of the platform, the tug allocation and path planning algorithms developed during the AEON project could not be integrated in the simulation environment used during the final validation session. This deviation implied two main consequences:

- **other algorithms already present in the platform were used**. Such algorithms do not guarantee the same level of optimisation of the AEON algorithms and thus had some unavoidable effects on the human performance of the ATCOs involved in the final validation.
- **the algorithms developed by AEON were not tested**. Nevertheless, inputs and feedback on their logic were collected during the three validation sessions and will be used to consolidate the final versions of the algorithms being described in D2.1 and D2.2.

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3 Human Performance Assessment Results

This chapter describes the results of the human performance assessments, as achieved in the three validation sessions above mentioned. For each session, information concerning the specific objectives and methodology in use are provided.

It is necessary to note that the present chapter focuses on the results produced by the Human Performance Assessment of the AEON initial concept of operation [1] instead of individual taxiing solutions. Aside from the initial validation session, in which it was crucial to focus on specific solutions to define perks and drawbacks of each technique, in the following two sessions, the focus was on the overall concept rather than the single solutions.

From an operational point of view, Single Engine Taxi (SET) do not significantly differ from traditional Double Engine Taxi (DET) procedures [2][1]. E-Taxi solutions impact the way pushback operations are performed, requiring additional skill from the pilot's perspective, and increasing taxi times due to lower speed profiles. On the other hand, the deployment of towing techniques increases taxi times due to coupling and uncoupling procedures. Nonetheless, tug vehicles may increase Ground ATCOs' workload due to the additional exchange of communications with Tug Drivers.

Being SET and E-Taxi solutions automatically managed by the algorithm for path planning, without any change in the current operating methods, the Human Performance Assessment mainly focused on the introduction of the new role envisioned by the AEON project, leaving to the D5.4 the consideration of costs and benefits associated with each solution.

3.1 Initial validation session

The initial evaluation session took place on September 2021 and aimed to profit by the support of the AEON Advisory Board (AB) members to collect some initial expert feedback on the preliminary AEON concept of operations for greener taxiing operations to be presented in D1.1 [1]. Twenty-four participants attended the meeting: eleven AB members, one representative from the SESAR Joint Undertaking (SJU), and twelve Consortium members.

Several important players of the aviation industry participated as AB members to this gathering providing meaningful contribution to the consolidation of the preliminary concept of operation. Among them, there were representatives from Eurocontrol, AIRBUS, SAFRAN, DSNA/CDG, The Schiphol Group, Smart Airport System, KLM, To70, Paris Airport and the SESAR JU.

3.1.1 Organisation and purpose of the initial validation session

As anticipated, the initial validation session aimed to collect feedback from the project stakeholders about the initial AEON concept of operations for greener taxiing operations to be presented in D1.1 [2]. With this scope, the agenda of the meeting focused on the main areas of interest of the project, namely:

- **OPERATIONS –** discussion about the current functioning of taxiing operations in normal conditions and the possible implications of the greener taxiing solutions considered by the project, namely autonomous (i.e., e-Taxi), non-autonomous (i.e., tugs), and Single Engine Taxi (SET), particularly on Human Performance.

- **COST-BENEFIT ANALYSIS –** initial considerations about the constraints and potential benefits associated with the three clusters of techniques studied by the Consortium.
- **TECHNICAL –** discussion about the different technical aspects composing the AEON initial operational concept (i.e., the multi-agent system for routing, the algorithm for fleet management, the Human-Machine Interaction and preliminary use cases) and how their integration could bring an added value in future airport operations.
- **SAFETY –** discussion about the criteria identified for the safety assessment, the related requirements, and the possible safety scenario (i.e., mechanical safety events, electric safety events, psychological strain safety events) associated with the AEON CONOPS.

The meeting brought the Consortium many insights into how to design and introduce the new AEON operational concept.

3.1.2 Validation objectives and success criteria

The main high-level objective of the initial validation session was to support the definition of the preliminary concept of operations. In order to further develop the AEON CONOPS, expert feedback was collected on each fundamental aspect related with the project solution. Depending on the inputs gathered and the insight produced, the Consortium then refined the CONOPS in sight of the next evaluation phase. Dedicated success criteria were associated to each high-level objective.

Validation objective		Success Criteria
Human Performance	To validate that the AEON concept does not negatively impact the required Human performance levels	Positive feedback from the stakeholders of the AB on the proposed concept of operations or, alternatively, suggestions of alternative ways to improve it.
Safety	To investigate the impact that the AEON concept is supposed to have in terms of safety and identify initial main issues	Positive feedback from the stakeholders of the AB on the safety scenarios, related requirements, and safety issues or, alternatively, ways to improve it.
Cost-benefit	To validate that the AEON concept enables a sustainable cost-benefit balancing for autonomous/non-autonomous electric taxiing systems	Positive feedback from the stakeholders of the AB on the CBA or, alternatively, ways to improve it.
Capacity	To determine the influence that the CONOPS might have on airport capacity	Positive feedback from the stakeholders of the AB on the impact of the AEON CONOPS on

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		airport capacity or, alternatively, suggestions on how to improve it.
Efficiency	To investigate that the AEON concept enables a suitable exploitation of airport capacity	Positive feedback from the stakeholders of the AB on the impact of the AEON CONOPS on airport capacity or, alternatively, suggestions on how to improve it.
Environmental impact	To investigate whether the AEON concept has positive effects on the environmental impact of taxiing operations	Positive feedback from the stakeholders of the AB on the proposed concept or, alternatively, suggestion of alternative ways to improve it.

Table 9. Preliminary evaluation objectives and success criteria

3.1.3 Validation methods

The validation methods used during the initial validation session with the Advisory Board were based on a mix of feedback collection, envisioning of scenarios and judgemental techniques, that were applied with a team of subject matter experts in a structured review of the AEON concept. The use of these techniques was suitable to the very low level of maturity of the concept of operations being validated.

3.1.4 Results

The results from the initial evaluation session carried out with the stakeholders of the Advisory Board targeted the discussion of the preliminary version of the AEON CONOPS, as well as the identification of possible operational benefits and drawbacks associated to the three taxiing solutions considered by the project.

Overall, the preliminary concept of operation discussed with the Advisory Board appeared to be in line with the expectations that the stakeholders had on the AEON progress and no major constrains emerged in relation to the validation objectives.

In addition, further inputs were collected to be considered in later stages of the project. These concern the following:

- The use of **tug vehicles** should be considered in relation to start-up times associated to each aircraft in order to have a clear view on the benefit associated to such a solution. Short distances may limit the benefit associated to this taxiing technique. On the other side, long taxiing times will have an impact on ground handlers' staffing levels, since part of the work force will be dedicated only to taxiing operations. The trade-off shall be considered in further stages of the CONOPS development.
- In previous studies, the **e-taxiing solutions** had been linked to Nose Landing Gear fatigue. This issue has been solved throughout the course of the year by the manufacturing companies. As a result, the aircraft may have to taxi at a lower speed, taxiing times may increase and airport

capacity decrease. Also, in the light of this kind considerations, the AEON concept aims to combine this technique with others to mitigate its disadvantages and encourage its adoption to reduce the fuel consumption of surface movements.

- **Single engine taxiing** operations were described as a mature solution which usage have been limited by safety issues that have often resulted in low pilot adoption. These issues often concern lack of manoeuvrability, balance, and/or runway configurations.

- **Electronic Flight Bag** (EFB) is not present on every aircraft; therefore, it may be advisable not to consider it as the principal means of communication between pilots and ATCOs. When not available, Pilots and ATCOs will interact through datalink communication and use radiofrequency only when needed. The EFB was excluded from safety assessment because it was not considered as the primary communication means in the AEON.

- In the near future, airport operations are likely to be distinguished into two categories, pertaining respectively to live traffic (pushback, taxiing, clearances, etc.) managed by the ATC, and non-live traffic (towing, empty tugs movements, etc.) managed by the APOC.

The Consortium employed all the feedback from the Advisory Board to refine the use cases of the greener taxiing techniques and consolidate the description of the Operational Concept (WP1), prototyping of HMI (WP3), and demonstrator integration (WP4).

3.2 Intermediate validation session

The purpose of the intermediate validation sessions was to explore and assess different alternatives for specific AEON tools (namely, modifications on A-SMGCS, Tugs Fleet Manager HMI and pilots' moving map) with the concerned stakeholders. It was also expected to identify possible showstoppers associated with the tools, roles, procedures, and the overall operational concept.

The intermediate evaluation was articulated in two sessions done respectively at Roissy Charles de Gaulle (CDG) - DSNA premises - and Amsterdam Airport Schiphol. Moreover, the results from this session benefited from the continuous evaluation of the AEON tools at ENAC. The session run at CDG involved ATCOs and professionals from Airport de Paris (ADP), while that at Schiphol engaged ground operational experts and people involved in the tug vehicles trials of the ALBATROSS project[3]. No ATCO took part in the session at Schiphol. At ENAC, two evaluation sessions were conducted with ATC instructors to validate the AEON tools features, the human-machine interaction, and consolidate the prototype design in sight of the final evaluation.

3.2.1 Validation Objectives

The main objective of this session was to gather a maximum of feedback from operational staff on specific solutions proposed to address the requirements formulated in D1.1 [2]. This session targeted

[3] https://www.sesarju.eu/projects/ALBATROSS

the validation of the concept of operations focusing on specific aspects of the solution. All the performance areas investigated within the project were evaluated, namely Human Performance (HP), Safety, Cost-Benefit, Capacity, Efficiency, Environmental Impact and Liability.

With regard to the HP assessment, the assessment covered the areas detailed in the SESAR HP Assessment process (HP)[5] and the validation objectives described in section 2.2.2.1, namely:

1. the consistency between **roles description and the human capabilities** or limitations
2. **the capability of the system to support human actors** in performing their tasks
3. the impact of **team communication and team structure** on human performance
4. other **transition factors** that may or may not support the human actors

In addition, a set of specific low level validation objectives was also defined and investigated during the study. These are listed in the following table. For each of the specific low level validation objective, indication of the associated KPA is provided in the first column, while the associated HP argument is traced in the fourth and one. The following high-level objectives were pursued:

Validation Objectives	Low level validation objectives	Success Criteria	Argument HP
Human Performance Safety Efficiency	Path planning algorithms Assess the path planning suggestions and study the effect of respecting or not the existing procedures. **Explore how specific operational context are suitable or not for such suggestion.**	The path planning algorithm is able to generate an efficient, conflict-free plan within X[4] seconds. The path planning algorithm is able to take into account constraints representing existing procedures and preferences of ATCOs. The path planning algorithm is able to detect in real time deviations from the current plan by pilots, and suggest changes to the plan to ATCOs	2.2
	Allocation algorithm performance **Computation time, ability to find solutions acceptable for ATCOs and TFM**	The allocation algorithm is able to allocate within minutes tug vehicles for all flights during one day of operations, indicating the optimal size of the fleet of tug vehicles (long/medium-term phase).	2.2

[4] At the moment of the study, 1 second was considered an optimal value. Further research will be needed to investigate the technical feasibility and operational acceptability of answering this timeframe.

		At the execution phase, the algorithm is able to allocate tug vehicles within minutes, by taking into account updates of the arrival/departure times of the flights.	
Human Performance	Operations Identifications by ATCOs. **Explore the design of the A-SMGCS to support ATCOs understanding the taxiing operations.**	The ATCOs are able to recognize an aircraft taxi technique, its status (towed or not, coupling or uncoupling) and if the aircraft is ready to take-off (engines started).	2.3
Human Performance	Tug Fleet Manager (TFM) allocation and supervision. **Explore the design of the TFM HMI to support the supervision and allocation of the tug vehicles.**	The TFM is able to understand the initial allocation plan and to modify it (cancel, update, or assign). The TFM understands the fleet status (allocated, attaching, waiting…).	2.3
Human Performance	Pilot operation support. **Explore the design of moving map and cockpit tools to support pilot using the AEON tools (tug vehicles, engines start-up time, speed profiles).**	Pilots are able to understand indications on appropriate time for starting engines if required (SET, e-taxi or tugs). Pilots are able to visualize and understand the computed ecological speed profile.	2.3
Human Performance	ATCO and TFM coordination. **Explore interactions supporting the collaboration between the TFM and the ATCOs.**	TFM is able to send an allocation request to the ATCO. ATCOs are able to visualize requests from TFM and make decisions (accept or refuse). ATCOs are able to indicate that a form of taxiing will not be possible to use.	3.3

Table 10. Specific objectives of the intermediate validation and related Requirements

The results achieved are provided hereafter.

3.2.2 Results for Arg. 1 - The role of the human is consistent with human capabilities and limitations

The role of human actors involved with the AEON concept was considered consistent with their resources and limitation. The description of roles was appropriate, although each airport declined the existing roles in relation to the operational context, arising divergences in the role definition (i.e., the Ground and Apron controllers at Schiphol). The roles and responsibilities were mostly clear following the opinion of the evaluation's participants.

3.2.2.1 (Arg. 1.1) Roles and responsibilities of human actors are clear and exhaustive

The different iterations with professionals from Paris CdG and Amsterdam Airport Schiphol confirmed that **the description of roles and responsibilities** provided in the AEON's preliminary concept of operation was clear and exhaustive in the opinion of the evaluations' attendees. The roles involved with the CONOPS are confirmed to be the Ground ATCOs, the Tug Fleet Manager (TFM), the pilot in command (PIC or pilot), and the Tug Driver (TD). A new interpretation of the ground-handling companies (GH) has raised during this round of evaluations. Nonetheless, this have not changed the way the roles were defined in the D1.1. TDs will have to take care of pushback/push-pull and for empty tugs, introducing the need for new skills. The PIC may require additional trainings to handle taxiing operations with tug vehicles, or to push back with e-taxi systems.

3.2.2.2 (Arg. 1.2) Operating methods are exhaustive and support human performance

The operating methods associated to each role have benefited from the information collected in the intermediate evaluation sessions. They resulted overall exhaustive, although it emerged that airports operate in ways that might depend on their specific layout. For instance, it appeared that in Amsterdam Schiphol the apron controls the ground vehicles while the aircraft are managed by the Ground ATCO. On the other hand, in CDG the apron and ground control handle both vehicles but in different area: the apron ATC controls the parking areas, while the Ground ATCO controls the taxiways.

The tug vehicles trials at Schiphol assigned the TD with different responsibilities than those conceptualised in the AEON concept. **The Tug Driver** (TD) at Schiphol took care of pushback/push-pull and for empty tugs. The PIC remained in command of steering the tug-aircraft combination. TDs was able to intervene if any hazards occur. Moreover, **the PIC** was in contact with Ground/Apron ATCOs to maintain an appropriate level of situational awareness and the TD was tuned on the same frequency.

Concerning ground-handlers' tasks, one of the options that the management of Schiphol airport is considering is to give them control of a pool of tug vehicles. In this case, their tasks will include those of the tug fleet manager as conceptualised in the AEON CONOPS. Although this might seem reasonable, this change could increase the work complexity of ground handlers, with potential fallouts on their workload. Moreover, the Ground/Apron ATCOs will have to interact with several TFMs that will be requiring clearances to perform their operations. The workload of ATCs may increase as a result, while the overall acceptability of the AEON concept may decrease. In light of these considerations, the AEON Consortium decided to consider the tug fleet manager and the ground handlers as two distinct roles in the AEON CONOPS. **The TFM** will continue to be considered the role who proposes tug vehicles and path allocation, then s/he will inform the Apron or Ground ATCOs according to the area where the aircraft is/should go.

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GHs in the future will see a decrease of demand for pushback operations because aircraft equipped with e-taxi systems will be able to do it autonomously. Nonetheless, this trend will be counteracted by the increased demand for specialised drivers to perform pushback with tug vehicles. Moreover, the introduction of tug vehicles will require Ground Handling companies to interact with the Tug Fleet Manager. As consequence the communication load of this role might increase.

Pilots of aircraft equipped with e-taxi systems will be required to manage pushback operations, taking the responsibilities that are now under the role of the GH companies. Additionally, the PIC will have to follow speed targets to optimise taxiing performance and copy with alerts when s/he does not respect the instructions provided by the TFM/Ground ATCO. Taxiing operations with tug vehicles may require additional competences to perform taxiing operations in a safety manner.

Ground ATCOs might have to interact with the TFM. As mentioned above, the workload that can result from the interaction of ATCOs with the additional tug vehicles confirms the need for a supporting role such as that of the TFM.

Results from ENAC suggested that the TFM does not need a direct view of the taxiways. Therefore, its position could be different from that of the Ground ATCO. However, they may need an additional means of communication to leverage the exchange of information about taxiing and tug allocations they would have had by staying in the same room.

3.2.2.3 (Arg. 1.3) Human actors can achieve their tasks

Following the way roles and operating methods were defined, most of the human actors resulted to be able to achieve their tasks. The Ground ATCO is the actor more concerned by the introduction of the greener taxiing techniques studied by the Consortium.

The Apron/Ground ATCO is confirmed to be the actor most affected by the introduction of the AEON concept of operations. The ATCOs from both airports reported to be already quite busy and raised some concerns about the possible additional workload that may derive from the management of the tug vehicles on the taxiways and, in particular, on the communication aspects. The tasks performed by the TFM to identify best possible de/coupling points might reduce the induced workload of having additional vehicles on ground.

3.2.3 Results for Arg. 2 - Technical support systems and HMI

The results from the Intermediate Evaluation show that there is an appropriate tasks allocation between the human and the machine. As mentioned above, the role mostly impacted by the concept has resulted to be the Ground ATCO, as it is expected to face higher workload level than the other actors. The quality of information provided should be aligned with the actors aimed to use it, while the design of the algorithms should have been improved to support the performance of the TFM.

3.2.3.1 (Arg. 2.1) There is an appropriate allocation of tasks between the human and machine

There is an appropriate tasks allocation between the humans and the machine. ATCOs appeared to benefit from several functions included in the AEON platform (i.e., path suggestions). The resulting workload levels and trust in the automated functions have been assessed in the Final Evaluation.

3.2.3.2 (Arg. 2.2) The performance of the technical system supports the human in carrying out their task

The AEON prototype resulted to be capable to support the actors involved with the CONOPS, although same observation arose regarding the type of information provided to pilots, GH companies and the TFM.

Concerning the information provided to the human actors, two topics emerged as relevant. They concern the information needed by the PIC and by the TFM.

Concerning the information needed by the PIC, the pilots from Schiphol suggested to employ Target Start-Up Approval Time (TSAT), rather than Target Off Block Time (TOBT), to provide PIC with valuable indicator to decide when starting the engines and cut fuel usage. The rationale of this proposal is because the TOBT is in general considered more useful for GH than for the PIC. Currently, this information is not provided to pilots who are used to decide on their own the time to start-up engine. However, this topic provided a valuable input for further stages of the project, particularly in relation to the information needed by the PIC to comply with his/her tasks. During our work with pilots at ENAC we found that having an indicator of the remaining taxi time or event better the actual planned time for departure would help starting the engines at a most appropriate time, hence saving more fuel.

On the other hand, the TFM should receive alternatives to reallocate tugs from the supporting systems when a delayed tug affects the following one. In similar cases, the system should also provide alerts to ensure the TFM situation awareness. Moreover, TFM should be able to browse past schedule to cope with unexpected delays in taxi schedule. The impact of such changes might introduce in terms of legal responsibility have been considered into the liability assessment (see Chapter 4).

3.2.3.3 (Arg. 2.3) The design of the human-machine interface supports the human in carrying out their tasks

The presentation of demos of the AEON prototype interface allowed to collect valuable feedback about its design and valid suggestion for improvements to be introduced in order to ensure it is able to support the different human actors in their activities. The visual aspects of the new vehicles on the radar HMI were appreciated and adequately conveyed the taxiing technique used by the aircraft or discriminate tugs from aircraft.

The TFM should be alerted when a delayed tug allocation affects the following one on the same tug. The labels and the timeline presentation required additional design efforts to simplify the information presented and ensure a better understanding of what taxiing technique shall be used by the aircrafts. It would be also advisable to provide TFM with average taxiing times.

Ground ATCOs stated to need timely and spatial relevant but non-intrusive notifications. They will have to get a clear visibility of the vehicles that are under their responsibility as well as the relevant information on the A-SMGCS to perform their activity in an efficient way.

Furthermore, the ATCOs involved in the evaluations at ENAC stated that tug allocation requests and information should be sent from the TFM at the last moment. The suggestion has been considered in the final evaluation. However, the results evidence this mean of communication was not adequate to create an appropriate level of situational awareness among the Ground ATCO and TFM, affecting team communication too (see Section 3.3.4.3).

3.2.4 Results for Arg. 3 - Team structure and communication

The following sections provide an overview of the impact of the AEN CONOPS on the interactions that happen at team level, namely among the actors involved in the AEON concept. These results show the impact the project solutions will have on the task allocation among the actors and the adopted means of communication.

3.2.4.1 (Arg. 3.1) Effects on team composition are identified

During the intermediate evaluation, no specific effect on team composition have been noticed.

3.2.4.2 (Arg. 3.2) The allocation of tasks between human actors supports human performance

The allocation of tasks between the different actors supports the human performance. The new role of TFM introduced by the Consortium is expected to decrease the workload of ATC and smooth the deployment of taxiing operations. Albeit the shared situational awareness between the TFM and the Ground ATCO, as well as that between the TD and PIC, might become pivotal to ensure the reduction of CO_2 and fuel consumption that is linked to sustainable taxiing techniques.

As a result, the coordination was expected to increase as the actors will require more information to understand the situation and take appropriate decisions. Low levels of situational awareness might become detrimental for safety and lead to hazards such as increased number of collisions due to the increasing number of vehicles on the taxiways.

3.2.4.3 (Arg. 3.3) The communication between team members supports human performance

The Ground ATC and TD are the roles expected to be overloaded by the exchange of communication with the different actors. The Ground ATC will have to interact with several PIC and TD to give clearances to move on the taxiways. On the same time the ATCO will have to accept the TFM requests.

The TD, on the other side, will have to interact with three actors the TFM that will assign him the missions, the Ground ATCOs to get taxiway clearances, and the PIC to coordinate pushback and ensure safety in taxiing operations. On abnormal or degraded operational mode, these exchanges may become critical, and the involved actors might start losing chunks of information that will result in a decreased situation awareness.

3.2.4.4 Results for Arg. 4 - Human Performance related transition factors are considered

This section describes the insight the Consortium gathered during the intermediate evaluation in relation to the acceptance of the operational concept, the changes in competence introduced and changes in staffing levels. The results show that the ATC and PIC are the roles that should adapt the most to the new concept of operations. ATC will likely have to interact with additional persons (the TD and TFM, the PIC will have to perform pushback operations with e-taxi systems, while the TD should be able to interact with Ground ATCO, perform pushback operations and respect the missions assigned by the TFM.

3.2.4.5 (Arg. 4.1) The proposed solution is acceptable to affected human actors

Ground ATC appears to be among the most impacted actors. Currently, they already have a huge amount of work to manage, especially in airports such as Paris CdG and Amsterdam Airport Schiphol. An extra person in the tower, for some ATCOs, is something to exclude. In their opinion, the TFM should be positioned in a different space and the situational awareness, as well as team collaboration, may be influenced as a result The final evaluation has kept this feedback into account to setup the RTS. The TFM and Ground ATCOs where therefore positioned in different rooms to understand the human performance implications.

3.2.4.6 (Arg. 4.2) Changes in competence requirements are analysed

Pilots and TD will need to be trained to perform pushback operations using respectively e-taxi systems and tug vehicles. The pilots will have to gather the competences to perform taxiing operations via e-taxiing.

TD will have to be trained to move on the taxiways and interact with the Ground ATCOs using its phraseology. They will have to know how to attach and detach the tug vehicle to or from an aircraft and how to intervene when a hazard occurs.

3.2.4.7 (Arg. 4.3) Changes in staffing requirements and staffing levels are identified

The introduction of tug vehicles will require higher Ground Handlers staffing levels than actual towing vehicles require. These will be the results of the increase of taxiing times introduced by the usage of tug vehicles.

3.3 Final Validation Session

The final validation session targeted the final assessment of the AEON concept of operations and tools, as well as the collection of inputs for the consolidated version of the AEON concept of operations (D1.2) and for the delivery of the final conclusions on the validity of the proposed solution.

During the final evaluation phase, the AEON concept (as designed in WP1) and prototypes (as designed in WP3) have been experimentally tested through simulation using the simulation platform (designed and implemented in WP4) to evaluate its operational feasibility and collect human performance data. As mentioned in section 2.4, the tug allocation and path planning algorithms developed by WP2 were not integrated in the platform used for the real time simulation, although their logic were evaluated during debriefings with the involved ATC.

3.3.1 Validation Objectives

This evaluation phase collected information related to all the performance areas investigated within the project, namely Human Performance (HP), Safety, Cost-Benefit, Capacity, Efficiency, Environmental Impact and Liability. The high-level goal for the Human Performance assessment in this phase was to analyse whether the concept enables proper human performance levels and if is considered acceptable by the involved actors [1].

According to the E-OCVM [4] validation objectives generation process, the HP high-level validation objective above mentioned was then decomposed into lower-level validation objectives that guided the final evaluation session. The complete list of HP validation objectives addressed is in Section 0.

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3.3.2 Results for Arg. 1 - The role of the human is consistent with human capabilities and limitations

The roles assessed during the final evaluation session were mainly the Ground ATCOs and Tug Fleet Manager. Although the exercise involved also a group of pseudo-pilots that performed the role of the Pilots in Command (PIC or more easily "pilot") and Tug Drivers, they were not included in the experimental setup due to limitations in the realism of their operations in the simulated environment.

3.3.2.1 (Arg. 1.1) Roles and responsibilities of human actors are clear and exhaustive

The participants in the final evaluation session affirmed that the AEON concept considers all the roles and responsibilities involved with its functioning. Nonetheless, the results from group de-briefing and questionnaires show up the need to clarify the role and responsibilities of **the Tug Fleet Manager and the Ground ATCO**.

During the RTS, the participants approached **the TFM** in two different ways. On the one hand, the TFM was played as a kind of flight dispatcher that checks the algorithms' suggestions and assign missions to the TDs. On the other hand, the TFM was played as an ATCO equivalent figure which tasks aim to support the performance of the Ground ATCO. These different ways to approach the TFM were influenced in the first place by the definition of the role itself and secondly by the fact that no tight rules were provided on how to manage the role and the associated tasks. On purpose, in the final evaluation the ATCOs involved were quite free to interpret the role in the way they considered most suitable to them. This was made to enlarge the point of view on the new role and produce results that kept into account the broader range of options.The freedom to interpret the TFM role brought to the identification of the two modes above whose positive and negative effects on traffic management and cooperation with the ATCO were extensively discussed with the participants. This double way of interpreting the role is also evident in the results from the general questionnaire, administrated at the end of each session, from which a high variability is registered on the participants' opinion about clarity and exhaustiveness of the proposed roles (Arg. 1.1.2., Figure 3). Four participants out of seven stated the description of roles and responsibilities covered the procedure they had to follow in a partial way.

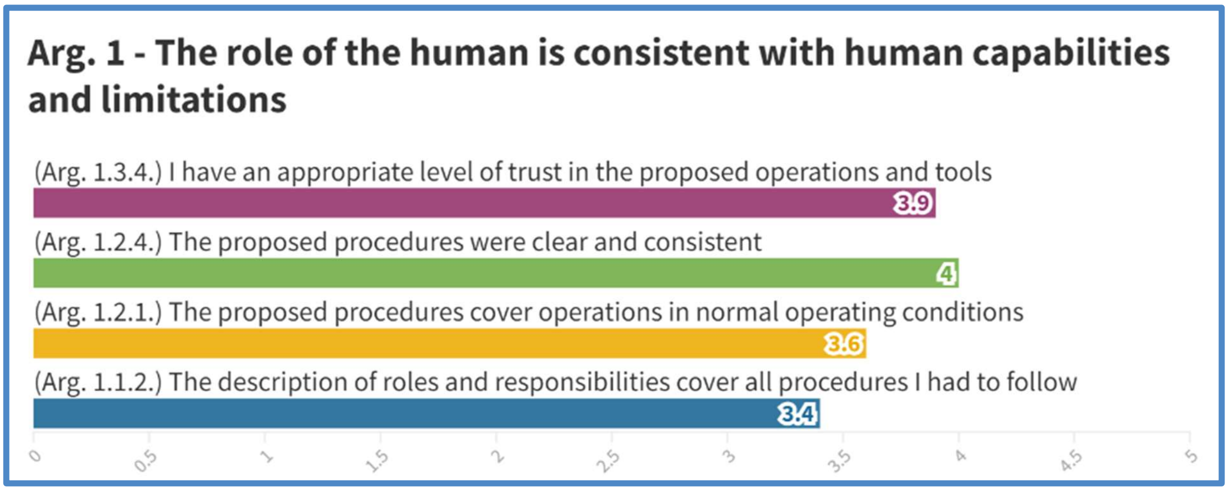

Figure 3. Results to the items related to Arguments 1 in the general questionnaire

(1= not agree, 5= totally agree)

Interestingly, during the de-briefings the participants who tended to interpret the TFM role in analogy to a flight dispatcher stated that one factor leading them to play the role in this way was their trust on the platform's suggestions. High levels of trust resulted also from the general questionnaire (Arg. 1.3.4., Figure 3).

As anticipated the two ways of managing the TFM was largely discussed with the participants in the RTS. In turn, this brought to wider discussions about the nature of the TFM itself, with the main question pointing out the doubt whether the role shall be played by an ATCO or not. From the information collected and also from the observation of the work done during the RTS, it seems advisable that the TFM have a certain knowledge as ATCO, thus possibly being part of the ANSP and located in the tower could be preferable. However, it is worth noticing that the role of the TFM as an ATCO equivalent may have been affected by the low maturity of the algorithm used for path planning and tug vehicles allocation. During the RTS it was used a simplified version of the algorithm. As consequence, the TFMs had the chance to play an active role in the optimisation of the fleet and to do it in a way that was supportive for the ATCO. The topic requires further investigations in later stages of the project.

No major impacts were observed concerning roles and responsibilities of **the Ground ATCO**. However, it is evident that the addition of the tug vehicles in the control area implied an increase attention to monitor the situation. As indication for next stages of the concept development it was evident that the Ground ATCOs and TFMs shall know in advance where the coupling and decoupling area are located as well as the way the TFM operates. The lack of this knowledge is considered detrimental for the Ground ATCOs' performance.

3.3.2.2 (Arg. 1.2) Operating methods are exhaustive and support human performance

As per the role definition, also the operating methods of the TFM shall be more clearly defined. In particular, it is advisable to clarify the specific strategy of tug optimisation used both for tug allocation and path planning, the communication with the tug driver and the management of tug allocation/reallocation in case of last-minute changes.

The participants involved in the simulation stated that the proposed procedures were partially able to cover all the operations in normal conditions (Arg. 1.2.1., Figure 3), though they were clear and consistent (Arg. 1.2.4., Figure 3). It is likely that the TFM role definition have influenced not only its own performance but also that of Ground ATCOs. The exhaustiveness of operating methods in normal conditions seem to be linked with familiarity with the CONOPS.

3.3.2.3 (Arg. 1.3) Human actors can achieve their tasks

The possibility for the Human Actors to achieve their tasks was affected by the uncertainties that were already identified concerning the roles and working methods and by some limitation of the platform. As a consequence, this argument could be partially assessed.

Ground ATCOs were able to perform their tasks but delays were frequently observed due to the RTS setup. Often, the pseudo pilots were not able to call (due to radio frequency too busy) when they reached an intersection or a specific point requiring transfer or new instruction which caused delays but was not on GND fault.

The use of the platform for **TFMs** was hard to understand, especially when they had to modify the tug allocations at in the first session (see Section 3.2.3.2). This led part of the participants to accept the suggestions provided by the systems with few modifications.

All the participants show high level of trust towards the AEON concept and the tools used during the simulation. The level of trust towards the algorithm suggestions could have led the participants to play the role of the TFM as a dispatcher. Only when the subjects familiarised a little more with the platform, they managed to play the TFM role more proactively and as an ATCO equivalent figure, supporting the Ground ATCOs.

The exchange of communication among Ground ATCOs, pilots and Tug Drivers, and the increase of vehicles on the ground are all factors that have to be consider as potential threats for ATCOs' performance. The coordination between the ATCOs and the other roles determined a number of misses such as aircraft waiting for clearances to take-off or reach the apron. Introducing a new role to which communicate (the TD) may have a bad influence on Ground ATCOs' workload.

3.3.3 Results for Arg. 2 - Technical support systems and HMI

The system usability resulted partially appropriate for participants to achieve their tasks. The System Usability Scale (SUS) shows average usability levels for participants attending the final evaluation session (M=67; results above 68 are considered above average and vice versa). The tasks allocation between the actors was adequate, though Ground ATCOs experienced a higher workload than that of TFMs. The platform performance was able to support the TFM in most cases, but some improvements will be needed to reach optimal levels. Similarly, the design should be advanced to support TFM performance.

3.3.3.1 (Arg. 2.1) There is an appropriate allocation of tasks between the human and machine

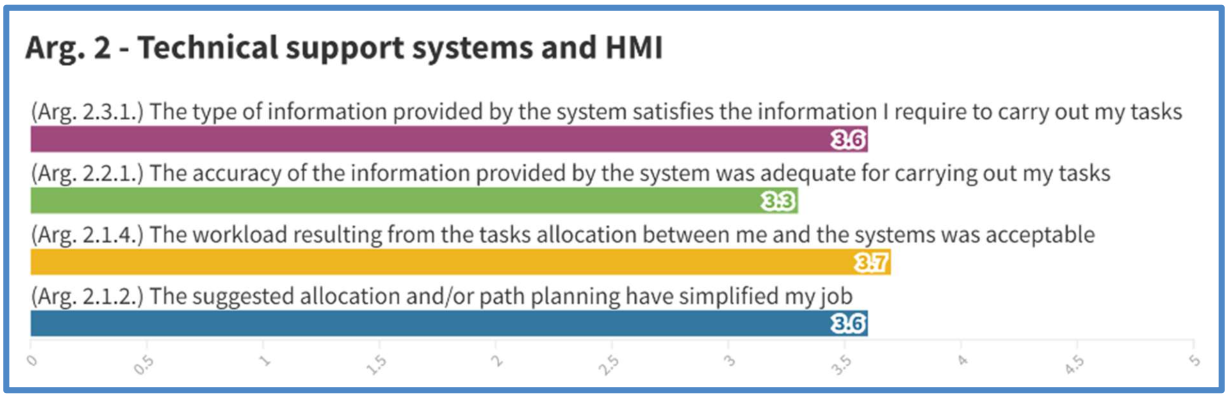

Figure 4. Results to the items related to Argument 2 in the general questionnaire

(1= not agree, 5= totally agree)

Ground ATCOs are more likely to experience higher workload levels than the TFMs (Arg. 2.1.4., Figure 4) even though these levels are largely acceptable (Bedford average score 3.3/10).

The option of adding tug vehicles dedicated service roads shall be further explored in order to allow the tug vehicles to use taxiways only when coupled with an aircraft and minimise their usage of the taxiways. Service roads may represent a mean to decrease ATCOs workload as they will allow TD to move on the surface without occupying the taxiways and therefore reducing clearances requests.

The opposite trend is shown **by the Tug Fleet Managers**, whose workload increased due to the delay generated in the second use case. When the TFM performed its tasks proactively, trying to prepare the work for the Ground ATCO, this last one experienced higher workload levels. Ground ATCOs had to manage a higher number of TD requests resulting from the optimal allocation made by the TFM, operating more in the execution phase than in the long/medium-term one. Even with a TFM working at a planning stage and in a different location, we can envision the same Ground ATCOs' workload levels. This shall be further explored into future research.

Some of the participants, influenced by their trust in the system, did not change the tug allocation even when considering it not optimal. They assumed that there was an optimisation algorithm undergoing and since they did not understand it properly. They preferred not to change its suggestions to avoid any cascade effect. Using the algorithm developed in the WP2 might have led to different results.

The Tug Fleet Managers often found the suggestions proposed by the algorithm for taxiing allocation reliable (Arg. 2.1.2., Figure 4). The ATCOs stated the algorithm for routing helped to understand the conflict between two routes and choosing how to manage the traffic on the ground accordingly.

3.3.3.2 (Arg. 2.2) The performance of the technical system supports the human in carrying out their task

The performance of the Human Machine Interaction (HMI) tended to support the operations of both ATCO and TFM although with some exceptions, such as the management of delay reported hereafter.

The TFM working position not displaying real-time data when aircraft or tugs were delayed hindered the TFM performances. The TFM requires the help of an algorithm to facilitate/optimize reallocations, providing suggestions that minimize fuel consumption and thus greenhouse gas emissions to the maximum, while ensuring optimal airport capacity (Arg. 2.2.1., Figure 4).

Moreover, changing the tug allocation was not always easy for the TFM, as well as the suggestions received from the AEON algorithms (Arg. 2.3.1., Figure 4). During the debriefing done after one simulation, a participant affirmed s/he had tried to swap the tugs allocated to two aircraft. However, using the functionalities currently available (see Section 2.4), s/he had to cancel the mission of the first aircraft in order to free the tug. Then, s/he cancelled the mission of the second aircraft and when s/he was ready for the new allocation, s/he realised that he forgot which was the interested traffic. A simpler and more straightforward swap procedure shall be supported by the HMI.

Since the performance of the algorithm for tug allocation and path planning strongly affects human performance, it would be advisable to repeat the RTS with the AEON algorithm developed in WP2 in place and see the effect on HP.

3.3.3.3 (Arg. 2.3) The design of the human-machine interface supports the human in carrying out their tasks

Even though the AEON prototypes and algorithms were not matter of the assessment due to their low level of maturity, they were a pivotal element of the RTS. Therefore, it is worth considering the influence some design aspects may have had on human performance during the runs to have a deep understanding of the results from the HP assessment.

Overall, the design of the human-machine interface was able to provide valuable support to the human performance. Even though, some aspects are recommended to be further developed to ensure improving the human-machine interaction. What is particularly interesting is how the information were provided to the different actors. Looking at the results from the General Questionnaire, it appears that the information quantity and quality was adequate to support the human performance (Arg. 2.3.1. and 2.2.1, Figure 4).

The observation during the various session indicated that it was not clear that only narrow body aircraft could have used tug vehicle as an option for taxiing [5]. The Tug Fleet Manager HMI indeed shown the heavy (H) and jumbo aircraft in lighter colour in the horizontal bar, without giving the possibility to allocate them to a tug vehicle.

The way the functionality was designed was not considered evident enough for the participants to clearly understand the difference and, more importantly, the purpose of having aircraft represented in their HMI that they could not consider. Future research shall better explore the topic, by adding tugs for H traffic (mixed tug fleet) and studying the interaction between the two, both in terms of traffic performances and in terms of usability and acceptability of the proposed HMI.

The way delayed traffic was represented did not emerge as clear and effective enough. Apart from the effectiveness of making the aircraft flashing for a short while (with no guarantee of situational awareness from the TFM), the issue was the absence of a key information concerning time required for un/coupling and the amount of the delay. Even though the delay can be obtained from the new schedule of the aircraft, this was not enough evident for the TFM, who tended to associate the delay to an action of rescheduling that s/he was supposed to do.

The pop-up messages sent from the TFM to the ATCO most of the time were not taken into account. When noticed, ATCOs tended to perceive them as distracting and accepted them by default without analysis (as considered not immediately affecting the work). Moreover, the pop-up notifications were not seen in a timely manner.

This functionality resulted from the intermediate evaluation as a tool to enhance the interaction between the TFM and Ground ATCO. The results from the RTS nevertheless suggest reconsidering it both in the purpose and the design of the HMI since it was not perceived as a communication tool as initially designed. The interaction between these two roles might improve via better integration of the modifications made by TFM in the information system. The participants also suggested enabling Ground ATCOs to send a request to stop the use of tug vehicles for a certain period (i.e., when traffic increases suddenly).

3.3.4 Results for Arg. 3 - Team structure and Team communication

The changes introduced by the AEON concept in the team structure led to moderate effects on human performance. The low maturity of the TFM and scarce definition of the Ground ATCOs' tasks had an

[5] This limitation was introduced in the simulation mainly due to technical reasons. 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 [2].

effect on the performances of both the actors. The RTS set-up might have played an important role in team communication, decreasing the shared situational awareness. The means of team communication envisioned by the Consortium did not appear to be sufficient to support the exchange of information between the TFM and Ground ATCO (i.e., TFM requests, radio and telephone communication with the Ground ATCO) and the matter would need to be further investigated.

3.3.4.1 (Arg. 3.1) Effects on team composition are identified

Even though the participants often stated that the role and responsibilities definition was clear, the observations during the final evaluation suggested a strong need to better define the roles and working methods to allow the TFM and ATCO to actually perceive themselves as a team and improve coordination. As a matter of fact, the introduction of a new role managing the tug vehicles on the ground suggested the ATCOs would have needed to coordinate with the TFM to reach an appropriate level of situation awareness. On the contrary, no direct communication was observed between ATCOs and TFMs.

The subjects of the experiments agreed that the procedures followed in the simulation were realistic (Arg. 3.1.1., Figure 5). ATCOs did not appear to be impacted much by the changes introduced, at least not in terms of increased workload (Arg. 2.1.4., Figure 4). The clearance requests from the tug drivers and the need to consider the movement of an additional type of vehicle may have however influenced the high values in the perceived divided attention measured through the SART Scale after each run (M=5.6, Likert 7-points). During the RTS observation, it happened several times that the ATCO started managing the TDs' allocation via the path planning tool. This is seen as a clear misinterpretation of the responsibilities of the ATCO's role and responsibilities as envisioned in the AEON CONOPS. The perception of the TFM as not relevant to support the ATCO (Arg. 3.1.2., Figure 5).

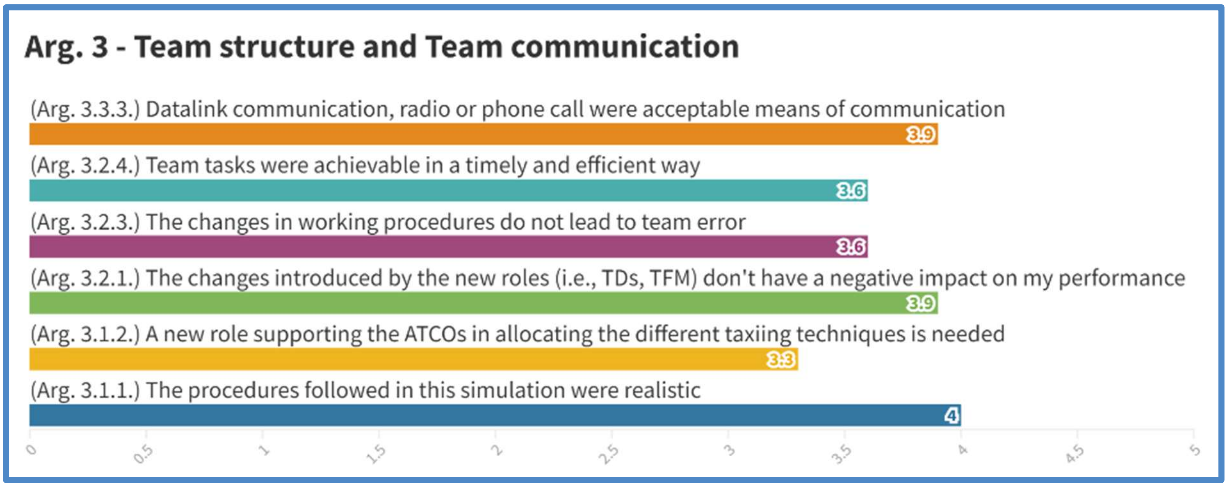

Figure 5. Results to the items related to Argument 3 in the general questionnaire

(1= not agree, 5= totally agree)

This perception could have resulted from the low level of interaction observed in simulation. During the simulations, the TFM and Ground ATCOs performed their activities in two separated rooms. This setting may have had a repercussion on the perceived situation awareness, which scored on average

24.5 out of 70 (SART 10D Scoring). Improving the role and working methods definition might have positive effects on the situation awareness and lead, therefore, to a better team collaboration.

The SART questionnaire administrated after each run shows high level of arousal (M=5.6; on a 7-point Likert Scale), concentration of attention (M=5.4), division of attention (M=5.7) and information quantity (M=5.3). The familiarity the participants' claimed to have with the situation obtained lower values than the precedents (M=3.8). The non-linear correlation between these indicators could mean that increasing the time spent using the platform and familiarising with the AEON CONOPS might decrease arousal, concentrated and divided attention and improve situational awareness.

3.3.4.2 (Arg. 3.2) The allocation of tasks between human actors supports human performance

The allocation of tasks between the TFM and ATCOs shall be more clearly defined. As mentioned above there was a certain level of flexibility in the way the roles were interpreted during the RTS. This largely affected the cooperation between the two roles, with some couples supporting each other very well and some others not. The results from the general questionnaires in some ways contradicts what has been observed during the runs and collected through the de-briefings.

The participants affirmed that the changes introduced by the new roles (e.g., the TFM and Tug Driver) did not have a negative effect on their performance (Arg. 3.2.1., Figure 5). Furthermore, the participants tended to report that on average the changes in working procedures did not lead to team error (Arg. 3.2.3., Figure 5) or inefficiency in team collaboration (Arg. 3.2.4., Figure 5).

These results may depend on the different ways the participants played the TFM role due to the low maturity of the role itself. Indeed, some couples were very effective and highly supportive of each other, while others were not. ATCOs took most decisions based on what was displayed on the screen, as well the TFMs. It appeared to be important to have the data always up to date with respect to reality of each one.

Starting at the medium-term planning phase, the TFM had more time to modify certain information such as the coupling/decoupling zone. The TFM worked upstream and tried to anticipate the work of the Ground ATCO to ease its tasks. However, the strategic planning carried out by the TFM did not always lead to an optimised tug allocation. Most of the time, the TFMs followed the suggestions given by the platform with just few modifications. Sometimes, it was possible to notice that the TFM could have adjusted the tug allocation to optimise the usage of the fleet, but it appeared not to see it, especially in the first session. With 31 aircraft planned to be towed, the some TFMs validated 42% of suggested allocations in the first session (26 assignments out of 62) and 89% in the second (55 out 62). Only two were cancelled in the first session, while 27 in the second[6]. The higher number of TFM validations resulted in more unexpected TDs' requests the Ground ATCO had to handle. In the future, it will be needed to ensure that the Ground ATCO knows in advance the impact the TFM activity will produce on its performance to plan ahead and ask the TFM to stop when the workload becomes too high or the exchange of communication too heavy to manage.

[6] This set of results is limited to the performance of the first pair of ATCOs (ID# 1 and 2).

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In order to understand whether the collaboration between the TFM and Ground ATCOs was actually impaired by the simulation setting and by poor dedicated communication features, it could be advisable to perform a RTS with the TFM and ATCOs in the same room or envision a solution that can improve the exchange of information between the two and their mutual situational awareness.

3.3.4.3 (Arg. 3.3) The communication between team members supports human performance

Looking at the results from the General Questionnaire it appears that means of communication employed by the TFMs and Ground ATCOs were appropriate to support their activities (Arg. 3.3.3., Figure 5). Even though during the RTS it has been often observed how the load of information exchange led the Ground ATCOs to partially lose the control of the situation.

As mentioned above, the query system (from TFM to ATCO) was not effective as expected. When a request arrived from the TFM to the ATCO, the last one did not have time to analyse it, or if s/he did, s/he accepted or refused all requests without paying attention because it was not relevant in the present.

The ATCOs stated they didn't care because they knew the tug driver would have called her/him when ready to drive. Therefore, the query system doubled the requests from the ATCOs perspective. Instead of receiving inquiries from the TFM, ATCOs could be allowed to stop tug vehicles usage for a certain period.

Concerning the phraseology, during the de-briefing it was pointed out that it is correct to avoid using the instruction "taxi" for the tugs. In particular, in order to distinguish the two vehicles, it is suggested to use "taxi" when giving clearance to the aircraft (including aircraft coupled to a tug) and to use "proceed" for the tugs.

3.3.5 Results for Arg. 4 - Human Performance related transition factors are considered

Transition factors related to the human performance observed in the final evaluation show the influence acceptance will have on the design of the TFM role. ATCOs prefer TFMs to be framed differently from them, i.e., as a dispatcher. However, the RTS shown how the different working positions and low level of interactions produced a scarce situation awareness even when the roles were played by ATCOs with the same background.

3.3.5.1 (Arg. 4.1) The proposed solution is acceptable to affected human actors

The AEON concept of operation was considered acceptable for the ATCOs involved in the RTS, even if the presence of the tugs on the taxiways will imply extra tasks and possibly workload. The acceptability of the TFM role largely depends on how it is designed.

In particular, full ATCOs may have difficulties in accepting to play the TFM role. It shall be designed as a different role (associated to a different licence, working position and work organisation). The suggestions raised by the participants were to consider the TFM as an airport operator, possibly less qualified than an ATCO but still with the minimum background to be able to support her/him.

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3.3.5.2 (Arg. 4.2) Changes in competence requirements are analysed

As mentioned above, the role of the TFM needs to be designed in terms of competences and skills required. This also has an impact on training and on the working place. This new role could be part of the ANSP (with a dedicated licence and a dedicated workstation in the tower) or not. The first option appears more appealing at this stage for a HP and safety perspective in order to smooth the cooperation with the ATCO.

The ATCOs shall know the performances and limitations of tug vehicles and take them into account while managing the traffic. This will have an impact on their skills and also on the required training. The TFMs must know the platform to operate efficiently. Tug drivers will need to know the airport very well, possibly better than the pilots.

3.3.5.3 (Arg. 4.3) Changes in staffing requirements and staffing levels are identified

The results from the final validation have shown the possibility for the TFM to be an additional ATC in the control tower. Together with the need for a specific license, this will require further resources to manage the fleet of tugs.

3.4 Summary of the Human Performance Results

Table 11 aims to provide an overall picture of the impact the AEON concept of operation will have on the performance of the involved actors.

Validation objective	Detailed validation objective	Criteria	Status	Rationale
VO1 | HUMAN PERFORMANCE				
To validate that the AEON CONOPS does not negatively impact the required HP levels	1 The role of the human is consistent with human capabilities and limitations	1.1 Roles and responsibilities of human actors are clear and exhaustive	**Partially OK**	The role and responsibilities of the TFM shall be further detailed and improved.
		1.2 Operating methods are exhaustive and support human performance	**Partially OK**	The operating methods of the TFM shall be clarified.
		1.3 Human actors can achieve their tasks	**Partially OK**	The actors partially achieve their tasks. The limitations, besides to issues related to roles and tasks definitions (1.1 - 1.2) were also due to platform usability,

				familiarity with the concept and situation awareness.
	2 Technical systems support the human actors in performing their tasks	2.1 Appropriate allocation of tasks between the human and machine	**OK**	
		2.2 The performance of the technical system supports the human in carrying out their task	**Partially OK**	The feature of the WP2 algorithms shall be tested to understand the impact on human performance. The algorithms employed in the RTS supported the actors' performance, although improvements were needed, especially for the TFM activity.
		2.3 The design of the human-machine interface supports the human in carrying out their tasks	**Partially OK**	The design of the HMI supported human performance, though some improvements are needed (i.e., displaying clear information regarding the size of aircraft and tug vehicles, increasing clarity regards delayed traffic, and giving the possibility to swap TD's missions)
	3 Team structures and team communication support the human actors in	3.1 Effects on team composition are identified	**Partially OK**	The maturity of the TFM role description influenced its performance and

	performing their tasks			that of the Ground ATCO. TFM are preferred to be distinct from ATCOs.
		3.2 The allocation of tasks between human actors supports human performance	**Partially OK**	The maturity of the TFM role description influenced its performance and that of the Ground ATCO. The TFM and Ground ATCOs shall be considered as a team.
		3.3 The communication between team members supports human performance	**Partially OK**	The means of communication provided in the RTS (TFM requests, telephone and radio) were not sufficient to support the TFM and Ground ATCO performance. Although the need for a communication channel was evident, at the same time the channel envisioned in the final simulation was not effective.
	4 Human Performance related transition factors are considered	4.1 The proposed solution is acceptable to affected human actors	**OK**	

		4.2 Changes in competence requirements are analysed	**Partially OK**	Pilots will have to manage pushback operations via e-taxi systems. TDs will have to be trained to guide tugs as well as un/coupling it with aircraft.
		4.3 Changes in staffing requirements and staffing levels are identified	**Partially OK**	The tug vehicles deployment may require higher GH staffing levels due to longer taxiing times. Higher staffing levels required to include TFM in the control tower.

Table 11. Summary of the Human Performance Results

3.5 Confidence in Human Performance Results

The present sections aim to illustrates the confidence in the results from the HP assessment, presenting in the first place the limitations affecting the Real Time Simulation and the quality of validation results.

3.5.1 Limitations of Human Performance assessment

Several limitations have influenced the human performance assessment and the results produced by the iterative process. First, the prevalent constraint to consider is that related to the assessment of a preliminary concept of operations that integrates technologies with different maturity levels. Indeed, the CONOPS and solutions brought several uncertainties that the AEON project has tried to minimise through the various evaluation sessions. This mainly affect the strength of the project results, which rather than constituting a solid conclusion to the research on sustainable taxiing operation should be seen an opportunity to draw new lines of research.

The HP results are also highly dependent on the peculiarities of airports taken into account in the evaluation process. Through the interaction with representatives from Paris CdG and Schiphol, the Consortium understood that each airport operates in a specific way, depending on the airport layout, for instance, and on other dynamics that concern the specific AOPs. The HP results should always be considered as specific to the operational contexts (Paris CdG and Amsterdam Airport Schiphol) where they were produced. Further research shall explore the results applicability to a wider, and more differentiated, group of airports.

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Due to the period in which the intermediate and final evaluation sessions happened, the ATCOs' availability was also a constraint limiting the most efficient organisation of the different sessions. ATCOs scarcity has influenced in a particular way the final evaluation phase, where it affected the Experimental Plan definition and variety of results.

The scarce ATCO availability didn't allow the Consortium to carry out two evaluation sessions with each pair of controllers. Three participants out of seven took part in the RTS following a different set-up than those who had the chance to participate in eight runs on two sessions articulated on two half-days. Therefore, some ATCOs had more time to familiarise themselves with the AEON concept and its prototype, while others had not. Furthermore, the number of available ATCOs didn't allow to make comparisons within the group, grasp potential effects of personal factors or generalise the results.

Regarding the exercise set-up, dividing the participants into two rooms may have affected situational awareness, team coordination and perception of the TFM as a role helpful to the Ground ATCO. The algorithms used in the simulation were not those developed by TU Delft. The lower quality of the suggestions provided by the system is likely to have influenced human performance and the optimal use of the fleet of tugs.

The lower level of automation provided by the available algorithm for tugs allocation and path planning (see 2.4) may have negatively influenced the actors' performance. However, higher levels of familiarity with the concept and airport layout might mitigate the impact of the quality of information provided without affecting workload.

Finally, the misalignment in the number of pseudo pilots and traffic volume have produced several bottlenecks and delays that have influenced the results collected through the data logs in terms of saved emissions and fuel consumption.

3.5.1.1 Quality of results from the HP assessment

The quality of the results is to be considered good despite the limitations encountered during the simulation exercises. The iterative process allowed the consortium to examine different aspects of the AEON operations concept and mitigate some of the uncertainties of the considered solutions and the concept definitions.

The first session allowed a better definition and consolidation of the preliminary version of the concept of taxiway operations. The intermediate sessions allowed the consortium to acquire more information about the airport context and the actors involved, understand the differences in how each airport operates, and, more importantly, how to leverage the AEON concept to various airports. Yet, the final session exercises allowed the project to collect relevant results from the human performance and the point of view of other areas such as liability.

The knowledge built during the various AEON CONOPS evaluation sessions will help future research to provide lines of development to the introduction of more sustainable off-engine taxiing techniques in the aviation industry.

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4 Liability Assessment

This part of the document reports the results of the application of the Legal Case methodology to the AEON solution. In particular, one of the main benefits of the early application of this method is the possibility to solve liability risks and problems with mitigations introduced at the level of operational concept, when this is still quite flexible and modulable at this stage.

In this regard, the purpose of the Legal Case application at the earliest stages of the design process is twofold.

- On the one side, this approach facilitates the detection of possible liability risks and problems of liability allocation among the different actors involved in the overall process of design, development, testing, training and operational usage of the new operational concept and associated tool, that may affect their acceptability within the organisation;
- On the other side, the Legal Case application allows the identification of suitable mitigation measures to be adopted to reduce such risks and problems.

4.1 The Legal Case

The Legal Case[7] is a methodology with an associated tool intended to support the integration of automated technologies into complex organisations, particularly in ATM. Its purpose is to address liability issues arising from the interaction between humans and automated tools, ensuring that these issues are clearly identified and dealt with at the right stage in the design, development, and deployment process.

This section provides an introduction to the method, showing its purpose, the way it is structured, and the process specifically applied in the reported project.

4.1.1 Purpose and scope of the method

The Legal Case can be applied to any ATM concept involving automation, i.e., the use of an automated technology. By automated technology we mean any "device or system that accomplishes (partially or fully) a function that was previously carried out (partially of fully) by a human operator". Thus, our notion of automation is not limited to "full automation", where an entire task is completely delegated to a machine, but rather covers cases where humans and machines interact, with machines supporting the human operator and, in some cases, enhancing and augmenting their capabilities. Two key elements are implicit in our characterization of automation:

- Automation is not all-or-nothing. In most cases, automated systems do not fully replace human activity but rather change it, in a way that depends on what tasks are supported by

[7] Contissa G. et al., Liability and automation: Issues and challenges for socio-technical systems, Journal of Aerospace Operations, vol. 2, no. 1-2, pp. 79-98, 2013

automation, on the extent to which human performance is involved, and on the impact on that performance.

- Automation is not tantamount to modernization or technological innovation as such. It covers only those cases where technology has an impact on human activities, and in particular on the interaction between humans and machines. For example, updating a computer with a more powerful system does not necessarily amount to increased automation, nor does an improvement in multi-radar tracking performance, which only implies a reduced radar-update time or more-accurate surveillance data. Our analysis is focused on the cooperation or co-agency between the human and machine when performing certain tasks and on the ensuing changes on the human operator's roles and responsibilities.

The Legal Case has been designed to be flexibly applied across all the phases of maturity in a system's life cycle. The methodology can be applied both proactively (from V1 to V3 of E-OCVM) and retroactively (from V4 on of E-OCVM). Depending on the maturity phase of the technology, the Legal Case analysis will rely on different types of background information, can be used for different purposes, and will provide different sorts of output.

The Legal Case is primarily intended for use in a proactive way during the design phase of a new operational concept/system, the point being to be able to address possible legal issues arising in the future from potential accidents or malfunctions. Indeed, the Legal Case is expected to provide important benefits if used early on in the design phase, when remedies can be implemented in a cost-effective way. The application of the proactive process is expected to be systematically and periodically applied during the design process in order to assess, at different levels of concept maturity, the legal issues of the ATM system being developed.

The Legal Case can also be used in a retroactive way, by applying it to existing technologies. Two such applications are actually possible. The first application is meant to identify possible future liability issues associated with a technology already in use, where the Legal Case may prove useful in addressing the legal risks the technology presents under the existing regulatory framework or in suggesting ways to improve that regulation. The second application concerns internal inquiries meant to determine liability risks that might be associated with incidents and serious incidents that have already taken place.

It is worth noticing that in none of these cases the Legal Case is intended to apportion liability and blame people or the organization, conversely it is intended to enforce the safety culture of the organisation making all the actors involved aware of the liability risks associated with their roles, tasks and activities and proactively identify suitable mitigations.

The method in fact entails the "design according to liabilities" approach, according to which liability is to be considered one of the inherent properties of the socio-technical system, in the same way as safety, human performance, security and environmental sustainability, and as such shall be taken into account since the earliest phases of an operational concept design. Indeed, a systemic approach shall be adopted to proactively investigate the impact of an operational concept or system on all these dimensions of the socio-technical system in which it is inserted.

4.1.2 The process

The Legal Case method offers a structured approach and process for the identification, analysis and mitigation of liability attribution issues related to the introduction of new operational concepts and tools in complex environments, in particular ATM.

The Legal Case process consists of the following four steps:

- Understand context and concept. This step involves collecting and elaborating background information about the object of the study so as to understand its socio-technical and normative aspects. The information collected concerns the operational concept itself and the context of its deployment, as well as the legal and regulatory aspects. This step includes the identification of the level of automation of the concerned ATM system, its impact on roles, tasks and responsibility and a set of use cases considered relevant for the following legal analysis.
- Identify liability issues. This step involves identifying the possible liabilities related to the object of the study and determining the associated liability risks.
- Address the liability allocation. This step involves analysing the acceptability of liability risks for all stakeholders, proposing also possible mitigations that may improve liability allocation, and making design recommendations accordingly.
- Collecting findings and Systemic Analysis. This step presents the results of the study, highlighting the liability issues associated with the object of study and the ways to deal with legal risks, as well as making further recommendations.

The diagram below shows the workflow of the Legal Case method.

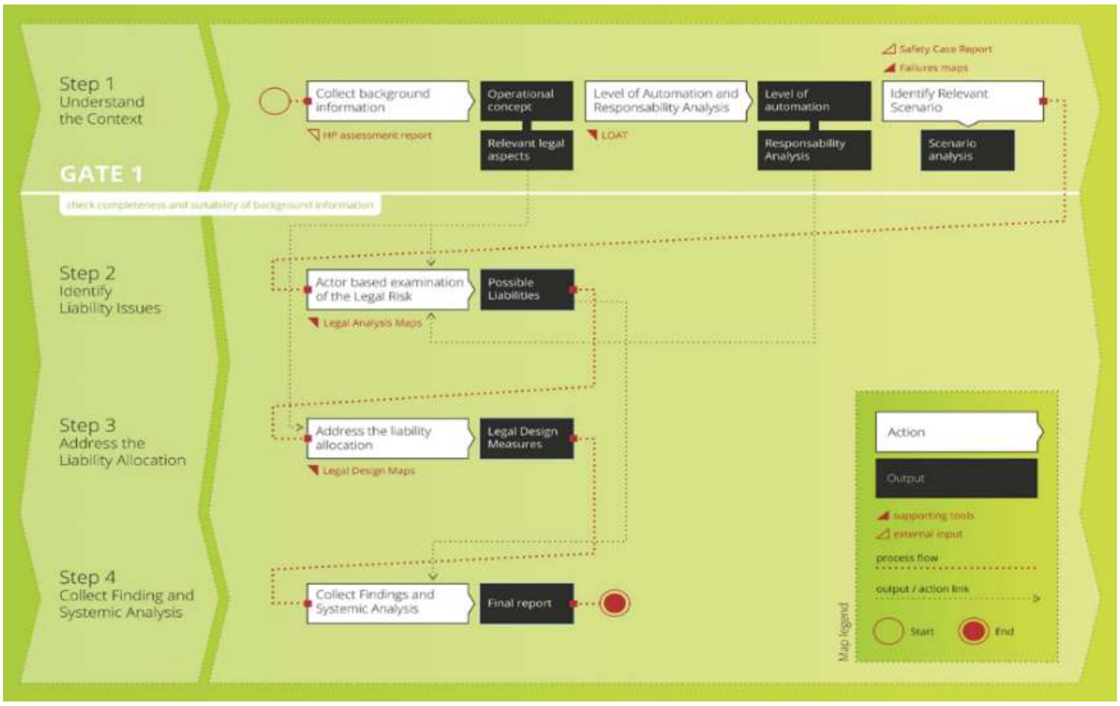

Figure 6 The Legal Case Process

White rectangles represent actions, i.e., sub steps within each step of the Legal Case. Black rectangles represent a flow of objects from one action to another, that is, the flow of the information produced in each sub step of the Legal Case. Bold arrows represent the main workflow. Light arrows represent other connections between objects and actions, that is, the information used as an input for each sub step. The Levels of Automation Taxonomy (LOAT)[8] table, and the legal argumentation maps used in the process (Failures maps, and the complete set of Legal Analysis maps) are also inputs and appear as red triangles.

The Safety Case Report and the Human Performance Assessment (HPA) Report are external inputs and appear as white triangles, meaning that – in case those reports are not available - the Legal Case can be applied without using them. Actually, should the Legal Case be completed before the Safety Case and/or HPA Case, it can be considered as an input for them as well.

4.1.3 Specific application to AEON

The application of the Legal Case methodology to AEON has taken into account all the inputs provided by the initial versions of the CONOPS (D1.1) as well as by the AEON Representative Use Cases (D1.5). In addition, the analysis also scrupulously considers all the insights provided and collected over the intermediate evaluations and the results obtained by final validation, according to an interdisciplinary approach.

4.2 Legal and regulatory framework

Taxiing is a crucial part of ground operations and involves several different actors. In this connection, liability issues are usually framed on individual bases. However, operations entangling complex concomitant and complementary tasks also need to be considered as a whole, according to a contextual understanding. Legal provisions about safety and security need to be taken into consideration in a proactive manner, consistent with the liability layout of each subject, as defined by national and international legislation.

On this premise, the following paragraphs present the relevant legal sources that define and shape these operations. It is noteworthy how aviation law is primarily based on international treaties and conventions. These international law instruments, in particular, aim at fostering a regulatory approach as uniform as possible. The undersigned states have a prominent political and legal duty to transpose these shared norms and principles into their domestic legal system. In addition, national legislators and judges should promote a uniform and consistent application of these latter into their national legal practice.

[8] Save L., Feuerberg, B. (2012), Designing Human-Automation Interaction: a new level of Automation Taxonomy, in De Waard, D., Brookhuis, K., Dehais, F., Weikert, C., Röttger, S., Manzey, D., Biede, S., Reuzeau, F., and Terrier, P. (Eds.) (2012), Proc. Human Factors of Systems and Technology 2012

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Looking at the EU legal context, these considerations are further nuanced by the peculiar characteristics of this legal system. According to its founding principles, EU law aims at harmonizing continental legislation and jurisprudence to strengthen the free movement of people, services, capital, and goods. Implementing these principles into the Single European Sky (SES) package, EU law often specifies international law principles, contextualizing and detailing these later according to the objectives and purposes of the EU integration and political strategies. Nonetheless, legislation in this sector primarily focuses on private law aspects and uniform safety requirements. Liability issues usually remain within the competencies of Member States.

4.2.1 Legal and regulatory framework for taxiing operations

As anticipated, the safe management of taxiing operations falls within the competence of the single European states, depending on transnational and international agreements.

4.2.1.1 Chicago Convention

The Chicago Convention (ICAO) of 1944 explicates the principle of national sovereignty in international aviation law. According to this convention, national States have "complete and exclusive sovereignty over the air space above its territory" (article 1). As a consequence, according to the following article 28, each national State "undertakes, so far as it may find practicable, to: (a) provide, in its territory, airports, radio services, meteorological services and other air navigation facilities to facilitate international air navigation, in accordance with the standards and practices recommended or established from time to time, pursuant to this Convention [and] (b) adopt and put into operation the appropriate standard systems of communications procedure, codes, markings, signals, lighting and other operational practices and rules which may be recommended or established from time to time, pursuant to this Convention".

In light of this, national States may be liable for the mismanagement of their airspace (and the respective necessary services) even when they have delegated their functions to air navigation service providers. In the absence of an international regime, eventual judicial decisions are regulated according to the law applicable where an accident occurred.

4.2.1.2 ICAO Convention Annexes

As per the Annex 2 of the ICAO Convention (Rules of the Air), taxiing is intended as any "movement of an aircraft on the surface of an aerodrome under its own power, excluding take-off and landing".

These operations, qualified as surface movements of the aircraft (Annex 2, §3.2.2.7), shall take place along taxiways, namely "a defined path on a land aerodrome established for the taxiing of aircraft and intended to provide a link between one part of the aerodrome and another". According to the recommendations contained in Annex 11 (Air Traffic Control Services, Flights Information Services, and Alerting Services), "such routes should be direct, simple and where practicable, designed to avoid traffic conflicts" (ibid., §2.14.1).

In light of the above, Annex 2 states the pilot in command (PIC) is the actor that above all the others is responsible for "taking action, including collision avoidance manoeuvres based on resolution advisories provided by ACAS equipment, as will best avert collision". More specifically, the document prescribes the priority rules as follows:

- “An aircraft taxiing on the manoeuvring area of an aerodrome shall give way to aircraft taking off or about to take off” (Annex 2, §3.2.2.6).
- “In case of danger of collision between two aircraft taxiing on the movement area of an aerodrome the following shall apply: a) when two aircraft are approaching head on, or approximately so, each shall stop or where practicable alter its course to the right so as to keep well clear; b) when two aircraft are on a converging course, the one which has the other on its right shall give way; c) an aircraft which is being overtaken by another aircraft shall have the right-of-way and the overtaking aircraft shall keep well clear of the other aircraft.” (ibid., §3.2.2.7.1).
- “An aircraft taxiing on the manoeuvring area shall stop and hold at all runway-holding positions unless otherwise authorized by the aerodrome control tower” (ibid., §3.2.2.7.2).
- “An aircraft taxiing on the manoeuvring area shall stop and hold at all lighted stop bars and may proceed further when the lights are switched off” (ibid., §3.2.2.7.3).

On the other hand, considering the position of ATSPs, Annex 11 specifies these latter have the responsibility “to issue clearances and information for the purpose of preventing collision between aircraft under its control and of expediting and maintaining an orderly flow of traffic” (ibid. §3.3.1(c)). This is to highlight how ATSPs, and pilots have shared responsibility – and, as a consequence, complementary liability risks – in the management of these operations.

It is noteworthy that, in this scenario, signatory States of the ICAO Convention generally must implement systematic and appropriate ATS safety management programmes to ensure safety in the provision of the ATS at airdromes (ibid., §2.26.1). However, considering the European context, national states here have implemented ANSPs as state-run or independent agencies. Therefore, liability issues concerning these providers may eventually involve even State as delegating subject. The liability of States, even in this legal framework, is primarily regulated by national and bilateral agreements or cross-border provisions.

4.2.1.3 Montreal Convention

Modernizing the rules previously introduced by the Warsaw Convention of 1929, the Montreal Convention of 1999 currently provides the international law liability framework for international carriage by air. The EU recognized and implemented the regime defined by this Convention as per the Reg. EC 889/2002 amending the previous Regulation (EC) No 2027/1997 on air carrier liability.

According to the article 17 of the Convention, “The carrier is liable for damage sustained in case of death or bodily injury of a passenger upon condition only that the accident which caused the death or injury took place on board the aircraft or in the course of any of the operations of embarking or disembarking”.

In light of this, carriers and companies can be vicariously liable for the actions performed under the responsibility of the pilot in command and the cabin crew. This responsibility, covering all the events that occurred on board the aircraft, includes even the phases of taxiing. The effects of this exposure, however, are limited to civil liability, imposing adequate insurance requirements. On the other hand, in light of the personnel nature of criminal liability, in case of death or injuries, this latter is usually charged to the individuals.

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4.2.1.4 Single European Sky

The EU established a common regulatory framework for airspace management on its territory, adopting a dedicated legislative package known as Single European Sky (SES). This initiative aims at ensuring and promoting the maximum possible regularity, security, safety and efficiency of continental air services. To pursue these objectives, the primary goal of the regulatory strategy is to consolidate and enhance the harmonization of national aviation law in all the domains related to the EU competences.

The structure of ATM in Europe is based on a series of regulations adopted by the EU, starting from 2004, that define the SES framework.

The initial basic regulations define the structure of the European airspace, on the basis of safety.

- the Framework regulation (EC No 549/2004) laying down the framework for the creation of the Single European Sky; 2914
- the Service provision regulation (EC No 550/2004) on the provision of air navigation services (ANS) in the Single European Sky.
- the Airspace regulation (EC No 551/2004) on the organisation and use of airspace in the Single European Sky.
- the interoperability regulation (EC No 552/2004) on the interoperability of the European ATM network.

This initial framework has been continuously expanded in the following years. Further regulations relevant to the ATS structure are:

- Regulation (EU) No 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency
- Regulation (EC) No 1108/2009 of the European Parliament and of the Council of 21 October 2009 amending Regulation (EC) No 216/2008 in the field of aerodromes, air traffic management and air navigation services
- Regulation (EC) No 1070/2009 improving the Performance of European Aviation System (Reg. (EC) No 1070/2009)

While the SES Regulations do not directly enter into the details of the liability framework, such legal instruments include a set of precautionary rules, namely safety rules aimed to prevent possible accidents (and related losses). In principle, precautionary standards and liability rules are closely related to each other. Indeed, liability norms are intended as legal remedies transferring the risk that not prevented beforehand. In particular, during the liability analysis, SES precautionary rules are taken into account to assess whether the conduct of the involved parties was negligent or not compliant with the applicable precautionary measures.

Moreover, there is an indication in the Service provision regulation (EC No 550/2004) on the "requirements for the provision of air navigation services". These requirements must be implemented by national laws in the EU member states and apply to the organisations that wish to become ANSPs.

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One of the listed requirements is "liability and insurance cover". Thus, the implementation of this requirement is to be found in national law.

4.2.1.5 Taxiing operations legal and regulatory framework within EU Law

The EU law and regulation implemented the ICAO Convention into the European legal framework with the intervention of the EU institutions, the Member States, and EASA. In particular, considering the principles defined in the ICAO Annexes, the EASA introduced and implemented the Standardized European Rules of the Air.

Focusing on taxiing operations, according to Regulation (EU) 2017/373 regards laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight (Consolidated version 2022):

- 'taxiing' means movement of an aircraft on the surface of an aerodrome or an operating site under its own power, excluding take-off and landing (Annex I, n. 237)
- 'taxiway' means a defined path on a land aerodrome established for the taxiing of aircraft and intended to provide a link between one part of the aerodrome and another (ibidem, n. 238)

In addition, Annex 1 of the Regulation (EU) 2020/469 of 14 February 2020 regards requirements for air traffic management/air navigation services, design of airspace structures and data quality, runway safety amended the section 4 of SERA 3210 as follows:

(i) The movement of persons or vehicles, including towed aircraft, on the manoeuvring area of an aerodrome shall be controlled by the aerodrome control tower as necessary to avoid hazard to them or to aircraft landing, taxiing or taking off.

(ii) In conditions where low visibility procedures are in operation: (A) persons and vehicles operating on the manoeuvring area of an aerodrome shall be restricted to the essential minimum and particular regard shall be given to the requirements to protect the critical and sensitive area(s) of radio navigation aids.

(iii) [...]

(iv) [...] vehicles on the manoeuvring area shall be required to comply with the following rules: (A) vehicles and vehicles towing aircraft shall give way to aircraft which are landing, taking-off or taxiing; (B) vehicles shall give way to other vehicles towing aircraft; (C) vehicles shall give way to other vehicles in accordance with air traffic services unit instructions; (D) notwithstanding the provisions of (A), (B) and (C), vehicles and vehicles towing aircraft shall comply with instructions issued by the aerodrome control tower.

4.2.1.6 Requirements for automated systems in the Single European Sky

In Regulation (EU) No 2018/1139 we find Article 12, where the need of certification in the design of parts is asserted, and Article 43, where this requirement is applied specifically in the context of Air Traffic Services.

The legislator developed this requirement further in Section VI and Annex VIII, with the following main points:

- 2.3.3. Automated tools providing information or advice to users shall be properly designed, produced and maintained to ensure that they are fit for their intended purpose.
- 2.3.5. Communication between air traffic services and aircraft and between relevant air traffic services units shall be timely, clear, correct and unambiguous, protected from interference and commonly understood and, if applicable, acknowledged by all actors involved.
- 3.3.2. Systems and constituents, considered collectively, separately and in relation to each other, shall be designed in such a way that an inverse relationship exists between the probability that any failure can result in a total system failure and the severity of its effect on the safety of services.
- 3.3.3. Systems and constituents, considered individually and in combination with each other, shall be designed taking into account limitations related to human capabilities and performance.

4.2.1.7 Personnel licensing

For personnel licensing, the primary regulatory source is ICAO Annex 1 (Personnel Licensing), where section 4.4 lists the requirements for Air Traffic Controller Licenses.

Within the EU licensing of ATCOs is a competence of EASA, and regulated by Commission Regulation (EU) 2015/340, with the aim of ensuring the highest possible standard. This piece of legislation furtherly implements these provisions and specifies the task of both national authorities and EASA. The driving role is given to the States, with EASA assessing the air traffic controller licensing system and compliance with its rules.

ICAO published multiple documents related to the duties and procedures for ATCOs, mainly with Doc 9426, "Air Traffic Services Planning Manual", and Doc 4444, "Procedures for Air Navigation Services - Air Traffic Management". These documents enter the finer details of the operational tasks and methods for ATCOs, like the interaction with the pilot and emergency procedures.

4.2.1.8 Certification

Since 2008, EASA has been responsible also for the certification of the design, production, maintenance and operation of aerodrome, ATM and air navigation services (Art 1, Reg. 1108/2009). This is a "total system approach," which takes into account all the aviation system components (products, operators, crews, aerodromes, ATM, ANS, on the ground and in the air) since they are all part of a single network (Recital 1, Reg. 1108/2009).

Another appropriate reference is Working Group 114 of EUROCAE, that defines "[…] technical standards, guides and any other material required to support the development of systems and the certification of aeronautical systems implementing AI-technologies".

4.2.2 Legal framework of liability

Before approaching the legal framework concerning liability, it is necessary a terminological premise. Legal scholars and practitioners use to distinguish the consequences of actions or omissions according to different criteria. In this connection, the three keywords in the analysis of the AEON legal framework should be accountability, responsibility, and liability.

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For the purposes of this report, legal and professional **accountability** within a relational context involves an individual or agency being held to answer for the performance expected by some significant "other". Accountability can furtherly be intended as a principle having a procedural dimension. From an operative perspective, accountability is framed on individual basis, and basically involves: (1) organizational relationship among two or more subjects, defined by law or by factual conditions; (2) a general duty to care about a process or procedure; (3) a general duty to monitor the regular (i.e., correct, and safe) functioning of a process or procedure; (4) a general duty to report and explain the organizational and operative choices related to a process or procedure.

On the other hand, **responsibility** refers to the duty or obligation to carry out a defined task or operation. This duty can be framed on an individual or collective bases, and the subjects involved answer their contribution and its consequences. For the purposes of AEON, responsibility implicitly involves: (1) full personal and situational awareness; (2) adequate professional capacity to carry out the assigned task; (3) relational and contextual understanding of individual contributions and the performance of the procedure taken as a whole.

Finally, **liability** is defined as the condition of being subject to legal consequences deriving from an action or omission. For legal liability to occur, there need to be certain preconditions: (1) a harmful event (2) linked to the action of a person, (3) who was acting in a professional role/task, (4) with no possible justification for the unexpected action. There are also the moral grounds of legal liability that, according to the just culture, should always overlap with legal liability: the person should have moral blame (liability) only when the harm was caused by consciously or recklessly violating a duty/task.

These three different profiles usually coexist. In some cases, these coincide and are referred to by the same actor. However, in some others, there is no perfect overlap. In these cases, thus, we may have different actors subject to diversified legal regimes. In particular, those in accountable positions can answer (secondary or vicarious liability) for the action and/or omission of those who took part into the procedures they have to supervise.

Likewise, a single and unique event can raise issues concerning different types of liabilities. In particular, aviation and ATM accidents typically engender:

- **criminal liability**, which presupposes an act (or omission) that violates national criminal legislation and is punished by imprisonment or a fine
- **civil (extra-contractual) liability** (or **tortious liability**), based on the intentional or negligent breach of the duty of care, which involves an obligation to redress the loss or injury caused by this breach
- **contractual liability**, which presupposes a breach of contract
- **State/administrative liability** presupposes the violation of a rule or regulation by a public officer who, while exercising his/her official powers, causes damages or harm
- **product liability** includes the liability of manufacturers and others for defective products
- **organisational liability** is a form of liability of the enterprise for organisational fault in case of injuries caused by commercial activities

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- **vicarious liability** refers to the fact that an employer may be held liable for the wrongful act of the employee, performed within the scope of his/her employment.

The categories of liability presented above can have a different impact on the different categories of operators that may be involved in an accident. We may distinguish the following classes of actors:

- **Physical persons**: the individuals who are directly involved in the provision of air services, namely, pilots, air traffic controllers (ATCOs) or managers of air services
- **Air carriers**
- **ANSPs**
- **Other service providers and actors**: bodies which support the provision of air services, such as technology manufacturers, airport operators, maintenance service providers, certification authorities, national supervisory authorities
- **States**
- **Insurance companies**

Since liability issues usually concern individuals, the report details the liability profile of each subject involved. As shown above, if legal persons basically can incur organisational and vicarious liability, those mainly exposed to criminal liability are the natural persons that materially perform the different tasks.

Aviation, however, experienced peculiar criminal offences. Usually, incidents and casualties are due to accidental situations that the involved operators can difficulty predict or control. Intentional wrongdoings are minimal and quite remote. Instead, the recurrent subjective element in events of this kind (accidents or incidents) usually refers to negligence, recklessness, or malpractice (including inexperience).

These considerations, therefore, suggest extending the scope of the analysis even to indirect criminal liability issues related to organisational and training gaps and deficits. Inadequate *ex-ante* and *ex-post* estimations of each operator's workload, as well as the lack of specific training sessions, may have detrimental consequences on the personal and professional capacities of the involved subject. And these organisational deficiencies can materially influence the state of mind of the actors performing their tasks.

Contextualizing these considerations within the AEON CONOPS, the following paragraphs present a reasonable outline of each actor involved.

4.2.2.1 ATCO and Pilot

ATCOs and pilots are usually considered as operators in an accountable position. These two categories of actors may be subject to criminal liability when intentionally causing the accident or when the accident was due to their negligent behaviour. In particular, when deaths result from an accident, they are often charged with manslaughter (non-intentional homicide).

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When ATCOs (or pilots) cause damages by not performing their tasks with the required skill and care, their employer (the ANSPs or the Air Carrier) will have a legal obligation to compensate for the damage based on vicarious liability.

This is why, as far as civil aviation is concerned, physical persons—in particular, pilots and ATCOs—are usually held liable to repair the damage only in connection with a criminal conviction; in all other cases, vicarious liability applies.

Finally, ATCOs and pilots may be subject to disciplinary sanctions towards their employers for violating their professional duties.

4.2.2.2 ANSPs

As anticipated, the primary legal reference for the liability regime of air carriers is the Montreal convention. It is worth noting how, over time, no other relevant international or regional liability regime comparable with this latter emerged. Consequently, at present, the liability of ANSPs does not find specific legal references. Additionally, no State has yet implemented any dedicated regulation to cover the liability issues concerning their ANS agencies. Regulation 889/2002/EU (amending Regulation 2027/1997/EU) only adopted the main principles of the Montreal Convention, stating, among the others, that a modern air transport system requires a regime of unlimited liability in case of passengers' decease or bodily injury.

In consideration of the sovereign nature of ANS, most national laws recognise the primary responsibility of the State, even if an independent body provides the services. However, practical modalities are different from one country to another. A second approach places the service provider on the front liability line: in this case, the claims must be brought against the service provider, but the ultimate responsibility of the State remains due to the lack of specific provisions on this matter. In a third approach, when the ANS functions have been delegated to a third party, the State remains liable only for damages caused by its own, direct fault.

ANSPs are also subject to vicarious civil liability for torts of ATCOs and managers and to enterprise liability for the safe management and supply of their services. Indeed, these agencies shall take due care of the safe arrangement and performance of their activities and procedures. Furtherly, they shall create a safe and efficient work environment minimizing the possibility of accidents. If they are not in with these best organizational and technical standards, the legal persons may answer for primary liability.

4.2.2.3 Technology providers

Manufacturers, when delivering defective goods, are liable to third parties who suffered damages under the regime of product liability, which involves a form of strict (i.e., no-fault) liability with additional exemptions (in particular, for design failures). They may also be contractually liable to the purchasers of their goods and services (failure to provide them up to standard may involve contractual infringement).

Organizations in charge of maintenance are usually subject to contractual liability towards the purchasers of their services. They are subject to fault (negligence) liability toward third parties.

Certification authorities may also be liable for providing wrong standards, compliance with which leads to defective products. Certification authorities are usually State entities, and their liability is a form of

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extra-contractual State liability: for instance, liability of EASA is governed by Article 31 (3) Reg. 216/2008.

4.2.2.4 Air Carriers

As mentioned above, the Montreal Convention regulates the liability for airlines in the event of damages to the passengers, luggage, or other goods during international flights. It entered into force in 1999, superseding the previous Warsaw Convention. The Montreal Convention considers two levels of liability in case of injury to the passengers: (1) liability up to 133.100 SDR irrespective of the airline's fault, and (2) liability in excess of such sum if it fails to prove that it (or the servants or agents employed) did not cause the damage for negligence or wrongful acts or omissions (Article 21).

4.3 Legal considerations about AEON

As explained above, the AEON solution aims to introduce a decision-making support software for a greater efficiency management of different engine-off taxiing techniques. The legal analysis of this solution, therefore, approach the legal issues concerning the use of this tool.

Note that from an operative perspective, the liability risk exposure of each technique involved falls outside the scope of AEON. For this reason, the liability assessment limitedly considered the vary circumstantial evidence. On the contrary, this focused on the operative consequences related to the AEON solution considered as a whole.

In light of the above, it is noteworthy to highlight just some punctual remarks about the three techniques involved. Single Engine Taxi (SET) and E-Taxi techniques do not significantly differ from the traditional Double Engine Taxi (DET) procedures. Indeed, in the case of SET, the actors involved only need to adapt the previous standards and procedures for the single-engine technique. Once available embedded E-Taxi solutions, instead, the main differences will concern the technical features of the aircraft. These differences, however, should have a limited impact on the liability regime of the actors involved. In this case, the pilot will remain the subject in charge of the material execution of the taxi: s/he will need the due training and licence extensions and will be accountable for the safe performances of the e-taxi-powered ground movements.

On the contrary, introducing towing techniques involves a considerable increase in the number of vehicles running on taxiways and service roads. The safe and efficient use of these vehicles implicitly requests the redefinition of the procedures previously in force and, when needed, the introduction of new ones. Consequently, this reviewing process imposes a redefinition of roles and figures and, therefore, of their related task responsibilities.

On these grounds, the legal analysis of the AEON solution will pay attention to the effects of the operative procedures required for the safe and efficient allocation and dispatching of these vehicles.

In light of this, the most evident novelty concerns the position of the TFM, the actor devolved to the safe and efficient management and allocation of tug vehicles. More specifically, the legal outline of this subject needs to be carefully analysed according to her/his new specific tasks. Consequently, the operative and legal regime of the other actors asked to collaborate with her/him needs to be reconsidered.

From a legal perspective, the analysis needs to focus on three main key issues, namely:

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- the definition of the liability outline of the TFM as a new actor involved in taxiing operations management.
- the consequences related to the introduction of this new role on the liability outlines and task-responsibilities of the other actors called to collaborate with this new entry.
- the role of AEON software in the decision-making process and the consequent liability implications.

From a methodological point of view, the legal analysis approaches the evolution of the role of each actor involved. Particularly, the study takes into account three sets of elements, namely: (1) the preliminary tasks description provided by the CONOPS (D1.1); (2) the insights obtained during the intermediate evaluation sessions in Paris CDG and Amsterdam Airport Schiphol AMS airports, and the final validation in Toulouse at ENAC; (3) the critical liability scenarios experienced or postulated from the results of the simulations.

4.3.1 APTOs, AOs and Airlines

The first category of actors considered by the flow of the operations described by the CONOPS includes APTOs, AOs and Airlines as key players in strategic planning.

In principle, their positions respectively present several points of contact. This is the reason why, for the purposes of the legal analysis of the concept, they are considered together. Structuring more analytical reasoning, however, two critical issues urge to be discussed and separately approached. On the one hand, the tasks-responsibilities of APTOs, AOs, and Airlines during the long/medium-term planning phase have to be analytically considered. On the other, there are the possible interdependencies among the legal regimes of these latter and the TFM.

Focusing on long/medium-term planning, the new operative method assumes that the AEON solution is integrated into the A-CDM. Once embedded the software provides a new HMI interface capable to coordinate various taxiing techniques, maximizing the efficient use of tug vehicles. During this phase, airlines and ground handlers receive information about tug vehicles allocations. They furtherly can express their preferences by accepting, rejecting, or changing the suggested planning up to 1 hour before the take-off/landing. Eventually, they can also define the taxiing techniques assigned to the rest of the traffic when not all the traffic has an assigned tug vehicle.

It is noteworthy that AOs and airlines have to provide and share this sort of information even in current taxiing operations. This is to say that AEON does not introduce completely new tasks but rather emphases the pertinence of the existing ones. Of course, the concrete adoption of this new solution attaches strategic relevance to monitoring and replanning tasks, since these contribute to a more fluid workflow. Nonetheless, other actors eventually have determinant decision-making power on in the scheduling operations.

In other words, with AEON, airlines and carriers have no (or limited) organisational discretion on the availability and allocation of tugs and taxi-bots. Indeed, their taxiing preferences are eventually assessed and scheduled by other subjects of the decisional chain. This induces us to consider the liability exposure of these subjects limited *per se.*

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Similar considerations apply to ground handling companies only involved in the scheduling operations of taxiing techniques. The operative tasks of these later, indeed, emulate the ones just described above.

On the other hand, as explained in D1.1, the use of tug vehicles could be a service proposed according to different economic models. Basically, the service can be offered either by the airport (APTO), the airline (AO) or the ground handling company (GH), depending on the strategic choices made for the implementation of AEON. The decisions may rely on several factors, like the environmental impact and the economic outcomes. In this regard, it could be efficient to share the vehicles over different companies with a pooling system, thus operated either by APTO or Ground Handling. On the other hand, AOs and Airlines could also have their own vehicles. The CONOPS assumes the company in charge of tugs and towing services answers to the good maintenance and operativity of the fleet at all times. In addition, the entire fleet management responsibility rests with the tug fleet manager, who should be an employee of the company that operates the service.

These different alternatives, however, may have significant consequences on the liability regimes of actors involved in the implementation of AEON. The role of the TFM, in particular, could acquire completely different outline, according to her/his contractual working position. More detailed information about this last issue is in the following section punctually dedicated to the TFM.

4.3.2 Tug Fleet Manager

As anticipated, the TFM is a new role introduced by AEON for the efficient management and allocations of towing vehicles for taxiing operations. More specifically, this role aims to ensure the best availability of the vehicles fleet by monitoring their status and handling maintenance operations. The TFM is in charge of providing towing vehicle on time, as the towing operation shall/can be undertaken as requested. In particular, the TFM has to choose and assign the towing vehicles to the aircraft 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 TD and ATCO joint responsibility to reach the aircraft to be towed on time for smooth operations.

According to the description provided by the CONOPS, the main tasks of the TFM concern the confirmation and allocation of tug/aircraft and the management of the fleet accordingly. S/he tactically changes the allocation in case of delays/problems in respecting the plan. Eventually, her/his choices and decisions about the allocation feed the path planning algorithm.

In light of this, TFM is a point of conjunction among the players involved in long/medium-term planning and those operatives in execution phase. This hybrid nature raises several issues about the fair definition of the legal outline of the TFM. On the one hand, this is called to play a management role devoted to the efficient allocation and dispatching of tugs according to the scheduled requests. On the other hand, s/he has a critical role for the safe execution of operations, especially in case of last-minute scheduling updates or over peak traffic situations. In particular, looking at these just mentioned scenarios, the TFM makes critical decisions strictly correlated to the task-responsibilities of the AC/GC– a condition that apparently requests a deep understanding of the role and functions performed by these latter.

To contextualize this new role within a consistent legal framework, we opted for an empirical and comparative approach. In light of the above description of TFM’s task-responsibilities, the report proposes a comparison among the empirical legal outline of this new actor with that of the already existing ones, namely a dispatcher and an ATCO.

Against this background, we can cluster the TFM's tasks into two main categories. On the one hand, there are tasks related to the professional monitoring capacity of this subject. It is particularly relevant her/his ability to assess the quality of the suggestions received by the software in terms of safety and efficiency. On the other hand, there are the tasks related to the allocation of tug vehicles and the communications with the tug drivers. All these operations may have determinant consequences on the quality of the information provided to other subjects that follow in the decisional and operative chain (AC/GC) and on their liability risks exposure.

Considering the two possible qualifications of the TFM, each of these options implicitly emphasizes one of these aspects more than the other, polarizing the understanding of the role alternatively on executive long/medium-term planning functions or executive phase.

The paragraphs that follow illustrate the legal regime potentially applicable to the TFM intended as a dispatcher and simile-ATCO, approaching the possible consequences for this figure and those that collaborate with it in terms of liability exposure.

4.3.2.1 TFM as a dispatcher

In light of the above, the first hypothesis to analyse considers the TFM as a dispatcher.

Generally, this category of subjects is suitable to include non-aircrew personnel with line responsibility for supporting the safe and expeditious departure of flights. From a liability perspective, therefore, we are before a generally flexible professional outline, with a non-specific accountability position and task-responsibilities defined according to her/his specific duties. On these grounds, this actor should be subject to a civil liability regime defined by her/his employment contract and covered by vicarious liability from her/his employer (presumably the APTO or AO and GH, according to the economic model adopted). From the criminal liability perspective, instead, s/he should be subject to general negligence standard and assessed according to a professional duty of care.

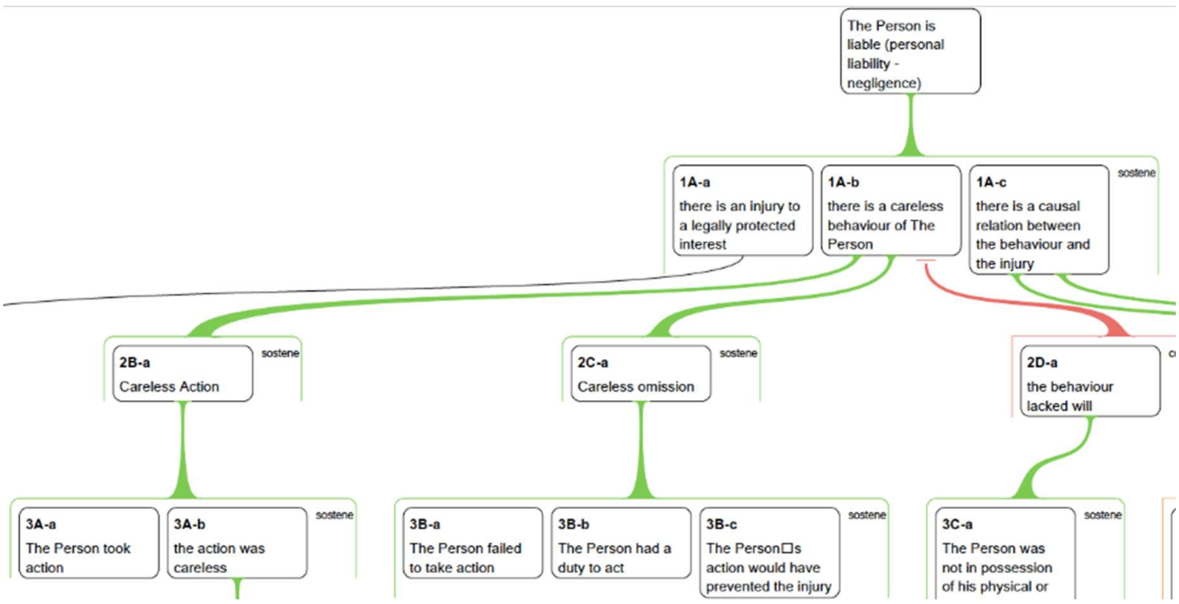

Figure 7. Map of generic negligence

The figure above describes part of the map for the assessment of generic professional negligence in aviation. Indeed, this should be the legal regime applicable to the TFM in case this actor would be qualified as a dispatcher.

A liability hypothesis can be confirmed if the following conditions are jointly satisfied: there is an injury to a legally protected interest; there is careless behaviour of the person at stake; and there is a (causal) relation between the behaviour and the injury. Some exceptions or counter arguments may be advanced, e.g., the fact that the person's behaviour lacked will.

Careless behaviour may consist of a careless action or a careless omission.

Individual's behaviour is careless when the person took action, and the action was careless. Carelessness is usually determined by assessing whether the action violates the standard of due care, which is the proper behaviour that a professional operator would have been required to follow in the given situation. Such expectations depend on the tasks assigned to the dispatcher, as well as on international and national laws, public or private standards and regulations, or even customs.

Individual's omission will be careless when the person failed to take action; the person had a duty to act; and the person's action would have prevented the injury. The content of the duty to act will depend on the tasks assigned to the dispatcher, as well as on international and national laws, public or private standards and regulations, or even customs.

In light of the above, the TFM intended as a dispatcher has no well-established accountability position. This is why it is reasonable to assume that, if qualified in these terms, the TFM is responsible for her/his own tasks but has context-limited proactive duties related to the procedures performed by actors not directly instructed by him/her.

4.3.2.2 TFM as an ATCO equivalent figure

On the other hand, the TFM could be equated and trained as ACTOs. This choice would rely on the proximity of their respective functions and task-responsibilities. In this case, the civil liability regime should be related to the contractual relationship between employer and employee, coupled with the professional insurance required by law. The criminal liability outline, instead, would be deeply impacted by the accountability duties of this category of actors. Task-responsibilities, therefore, should be considered beyond their nominal value and generally extended to the entire procedures, considered as a whole. This would include a general supervisory duty on the appropriate performance of other subjects' tasks (e.g., tug-drivers).

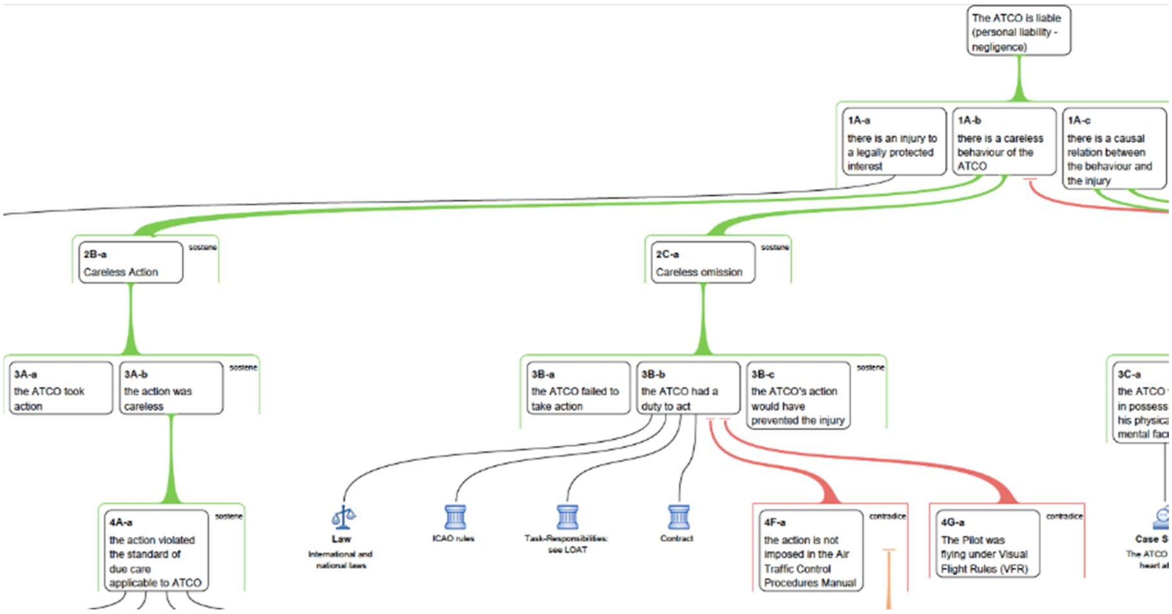

Figure 8. Map of ATCO negligence

The map above describes part of the map used for the ATCO liability assessment. At a glance, there are some similarities to the general negligence scheme. Even in this case a liability hypothesis can be confirmed if the following conditions are jointly satisfied: there is an injury to a legally protected interest; there is a careless behaviour of the person at stake; and there is a (causal) relation between the behaviour and the injury.

The criteria previously described for assessing carelessness, however, are set out with greater detail by international and national laws (such as navigation codes) public or private standards and regulations, or even customs. In addition, ATCOs professional standards are carefully and systematically defined by the Air Traffic Control Procedures Manual. In this regard, a possible exception may be based on the argument that the particular action omitted by the ATCO is not imposed in the Air Traffic Control Procedures Manual. In fact, in several legal cases (especially in the US) the controller who has fulfilled his obligations (as imposed in the manual) has been cleared of further liability.

Hence, if qualified as a simile-ACTO, the TFM may incur a sui generis accountability position. Beyond her/his specific tasks and the related responsibilities, in this case, s/he may also be considered accountable for the tasks performed by other operators and subject to a general duty of care and proactive attitude to monitor and prevent potential risk situations.

In principle, both these options are plausible per se. However, the choice between these two should take into account the consequences on the liability risks exposure of the other subjects involved, especially the ATCOs.

4.3.3 ATCO

It is worth noticing that ATCOs are the last link of the decision-making chain on taxiing operations. Indeed, the actors that follow – *e.g.,* pilots, ground crew, and TDs – usually have just a context-limited and other-directed understanding of the surrounding situations. In addition, performing their tasks, these latter are bonded by the clearances provided by the ATCS. Notoriously, in all these scenarios, consistent EU national caselaw assumes that ATCOs are responsible not only for their own tasks but are accountable even for those performed by the other subjects that they instructed.

According to the CONOPS, the ATCOs involved (in principle, the GC and AC) have a dedicated interface/dashboard. The device provides them information about the taxiing technique assigned to the aircraft and the path to be followed. Controllers are furtherly in charge of providing clearances to pilots and monitoring the correct carrying out of taxiing operations.

At a glance, segmenting the single tasks outlined in this brief description, ATCO has three sets of duties. First of all, s/he has to follow up on the information received by the fleet manager. Later, s/he has to validate the decisions made by this former operator according to traffic and safety conditions. Eventually, s/he has to provide the clearances to pilots, supporting them in taxiing operations. To do his/her job at best, the ATCO thus needs adequate information about the work previously done by others. Otherwise, s/he risks failing in her/his accountability and professional duties of care.

In light of this, ATCO's criminal liability regime is consistent with the considerations provided in the previous paragraphs. Careless actions and omissions include all necessary or appropriate interventions to avoid injuries or offences to a relevant legal interest (people, properties, and services).

This is the reason why the introduction of AEON warms to take into consideration two complementary needs. On the one hand, there is the need to maintain and preserve the material ex-ante and ex-post checking and assessing capacities of the ATCO. This, indeed, would allow better compliance with the accountability duties related to the role of these actors in taxiing operations. On the other hand, there is the need to avoid a potentially risky overload of information for the operators, and this is why some procedures tend to be automated.

Nonetheless, since these activities hinge on planning and execution phases, potential ATCO's carelessness may depend not only on her/his own behaviour but even on the poor quality of the information provided by the fleet manager and/or elaborated by AEON software. This is why the different legal regimes applicable to the TFM, and the consequences that her/his qualification may have a considerable impact on the liability risks exposure of the ATCO. Indeed, if the TFM would be qualified as a dispatcher, the subject accountable for the correct performance of taxiing operations considered as a whole, would be the ATCO only. If instead the two figures would be equated, this accountability burden – and the consequent liability risks – would be apportioned between the two, according to their specific fields of action.

4.3.3.1 Consequences of TFM legal qualification on ATCO's liability regime

As previously explained, the TFM plays a critical role even in the operations execution when s/he has to collaborate with GC/AC and tug drivers. From the legal perspective, in particular, the interactions between the TFM and GC/AC are one of the most delicate aspects of the CONOPS due to the evident intersections and conjunctions among their different tasks-responsibilities.

In light of the above, it is reasonable to assume that if the TFM is intended as a dispatcher, the ATCO should have full control over the information used and provided by the former since s/he is the subject finally accountable for all the following procedures. Notably, this option would implicitly involve a considerable increase in the ATCO workload and a rise in the liability risks exposure as a consequence of these additional tasks.

On the contrary, if the TFM is intended as a more proactive subject with more sharpening tasks in operations execution, this would suggest assimilating her/his liability regime to those in use for ATCO. In this scenario, TFM should take care of tugs allocation and dispatching, directly providing tug drivers' instructions for reaching the GC/AC control area. The GC/AC, instead, would be accountable for taxiing operations only and should focus on ground movements in her/his control area, providing clearances for towing operations only. At least in principle, the latter shall be the best option from the liability apportionment perspective.

These assumptions need careful consideration, especially in light of the results obtained during the final validation sessions. As previously explained, the testers had to play the role of TFM in low and normal traffic conditions, avoiding critical congestions or problematic situations. Approaching the proposed scenarios, testers, in practice, generally understood and interpreted the role of TFM in a passive way, monitoring the suggestions and limiting their interactions with the AEON system to the minimum necessary. They instead focused on the dispatching operations and communications with tug drivers, giving priority more to the executional nature of the role and less to its strategic potential.

Comparing the cases used for the simulations with those initially considered in the D3.1, it is notable a lower level of complexity that possibly influenced testers' behaviours. There are reasons to believe that, considering the issues commonly experienced approaching more complex scenarios in real operations, probably this complacent attitude would be overcome by a more proactive approach to the tasks.

From a practical point of view, a more proactive interpretation of the role of TFM would relieve the workload of the ATCO, anticipating and solving potentially critical situations. Nonetheless, if qualified as a dispatcher, the tasks performed by the TFM in any traffic conditions would put the liability burden on the shoulders of the ATCO. This latter, in case of problems, should be able to check the information received and make the due adjustments according to the ongoing operation's needs. Indeed, the controller should have a specific and far-reaching duty of care over the information provided by the TFM, as the subject eventually accountable for the safe and efficient execution of taxiing operations.

On the contrary, if equated to an ATCO, the figure of the TFM would be more autonomous from both a factual and legal point of view. If these actors have a mutual and complementary understanding of the respective tasks, they could cooperate more efficiently and safely. Not least, from a legal point of view, the liability apportionment between the two could be more well-balanced, thanks to the higher situation awareness ensured to the TFM.

To conclude, from a legal standpoint, the role of TFM should have a mitigating outcome on the liability apportionment related to the introduction of the AEON solution. A subject specifically devoted to management, allocation and dispatching of tug vehicles, indeed, implicitly exonerates ATCOs from these new collateral duties of taxiing operations and the connected liability risks. In addition, the proactive understanding of this role has the main objective to ensure and promote an expedited and ordered flow of air traffic, especially in case of contingencies and traffic peaks. In this regard, the flexibility and responsiveness of a human agent could be more profitable for a rapid and safe resolution of unexpected occurrences without excessive impact on the workload of ATCOs.

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4.3.3.2 The possible impacts of automation of TFM's tasks on the ATCO's liability regime

The role and functions of TFM present several challenging points even related to the novelty of this figure. As explained above, if intended as a dispatcher, this actor finally has limited tasks, basically related to the mechanical checking of AEON software suggestions.

In light of this, some stakeholders represent the possibility of fully automating the functions attributed to this new actor, enhancing the quality of the software for tug vehicles allocations and route definitions strategies. This solution would have the primary advantage of promoting the more efficient use of the tugs fleet and optimal planning and management of taxiing operations. Furthermore, automation would avoid duplications of roles and functions.

At a glance, this option addresses some of the qualification issues presented in the previous paragraphs. However, the increasing level of automation raises several other concerns about liability apportionment among the many subjects involved in taxiing operations.

A high level of automation in the allocation and dispatching process would substantially change the nature and function of the AEON system. Indeed, the software could not be any more considered as a decision support but as an autonomous system that materially collaborates with the human agents involved in the procedures.

Of course, high automation solutions can be declined and nuanced differently according to the contexts, even requiring a scalable intervention of humans. Nonetheless, task automation basically tends to marginalise the roles of human actors. Moreover, even when these latter have to intervene, they need contextual and operative information about the situation they have to manage, often experiencing difficulties related to HMI. In this regard, the attribution of liability would depend on the different characteristics of the highly automated system at issue and the role of the human actors involved.

AEON solution, at present, has a maturity level that does not allow a comprehensive analysis of these scenarios. However, intuitively, the figures mainly impacted by this hypothesis would be the ATCOs and tug drivers, first, and secondly ANSP, APTOs and manufactures. All these actors indeed have tasks directly related to the ones in charge of the TFM.

Generally, if from an operative standpoint, the critical aspects concern the risks of human complacency, technical biases or failures and HMI design defects, the most relevant legal issues approaching the liability risks concern transparency, accessibility and explainability. These three keywords respectively stress the necessity of transparent systems and interfaces (i.e., known and intelligible by the human agents), accessible operative rationale in the interactions with the machineries, and explainable results ready to be questioned and challenged by the competent operators.

Keeping this in mind, ATCOs and tug drivers basically should deal with instructions provided by software that analyses information and scenarios autonomously, and they should adapt their behaviours consequently. In other words, human actors, on the one hand, should be in the position of relying on the information provided by the tool. However, to avoid complacency, they should be able to challenge the results obtained, always having available and significant insights about the logic followed by the algorithms implemented by the software. A critical factor concerns human inhibitions to make divergent decisions from the one suggested by the tool and the related legal consequences for actions or omissions motivated by uneasily detectable biases and/or complacency.

In principle, from a technical standpoint, adopting of a highly automated solution is plausible, under the condition that the algorithms and software at stake satisfy the over mentioned transparency, accessibility and explainability requirements.

Nonetheless, from a legal perspective, this hypothesis is not so easy to implement. The automation of tugs allocation and dispatching implicitly involved a not negligible increase of liability risk exposure, especially for ATCOs that have an accountability position. The decisions of these actors – as well as of tug drivers – indeed, are factually informed by a default option, that in critical contingencies could be challenged difficulty due to the material lack of time in the performance of operative tasks.

Paragraph 4.3.6 will present the consequences that these forms of automation may have not just on individuals, but even on organisations and manufacturers' liability risk exposure. Nonetheless, we can anticipate that ANSPs and APTOs, considering the full automation of the role of the TFM, firstly should take into account if they can ensure adequate organisational and technical standards and reasonable investment to improve the safety of the product at stake. In particular, they should bear in mind the substantial impacts of this kind of solutions on the expected ATCOs' task-responsibilities performance. Risks of complacency and defective or inefficient bias detection, in this regard, deserve scrupulous attention. In other words, organisations should be in the conditions to assess if their structure may be able to profitably embed the use of these technologies in their current procedures and practices, and if the solutions available on the market fit with the above-mentioned requirements.

4.3.4 Tug Driver

Tug drivers belong to a specific category of ground handlers. Their tasks are primarily devoted to ensuring safe and fast coupling and decoupling operations and ground movements of aircraft by towing. They basically have executive functions and are supervised by competent ATCOs. Following the instructions received, they also communicate and collaborate with pilots and ground handlers for the joint execution of ground movements of the aircraft which are limited to pushback operations.

Usually, the TD is primarily involved in pushback operations. Once the pilot 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 as per either promulgated standard procedures or as specifically agreed beforehand.

In these operations, the responsibilities of the ground crew team to carry out the pushback includes ensuring that no part of the aircraft structure will impact any fixed object or other aircraft and may involve 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 communication with the person with the aircraft responsibility in the flight deck.

The concept of AEON attributes to these actors a relevant and more prominent role, extending the scope of their assignment from pushback to taxiing operations, considered as a whole. In this scenario, if coupling and decoupling tasks remain substantially unvaried, other elements may raise other liability issues.

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In principle, according to the CONOPS, the introduction of tug vehicles should not severely impact the logic of these operations and the rationale of the current liability apportionment. Most aircraft might require no modifications to use the tug vehicles. Taxi operations with this innovative system should be essentially transparent to the pilot by allowing the PIC to steer the aircraft using the tug vehicle through the aircraft tiller while controlling speed through the normal aircraft brakes.

However, the current use of these vehicles for taxiing operations induces us to consider other potential issues. If in normal conditions, the description provided by the CONOPS does not present relevant liability problems, in cases of emergency, the scenario may considerably change.

According to the stakeholders' experience, before a critical scenario, the tug drivers indeed could be in the position of intervening, supporting the pilot in handling the unexpected situation. Figuring these eventualities, however, these two actors should cooperate in performing tasks commonly under the formal responsibility of the pilot only.

In light of these material issues, at least in the early stage of implementation of AEON, these possible forms of collaboration may need particular precautions in order to ensure a fair apportionment of liability between the pilot and TD in the towing phase.

4.3.5 Pilot

Pilots' new tasks introduced by AEON require them to follow the instructions about the taxiing techniques to be used and the path to be followed, including coupling and decoupling and engine warm-up and cool down. In light of this, the interactions and information sharing between pilots and ATCOs are well-defined by professional manuals. This guidance potentially can be easily transposed into the AEON CONOPS.

These assumptions are valid for all the three engine-off taxiing techniques (SET, e-taxi and tug vehicles) considered in the AEON project. Nonetheless, as anticipated above, from a practical point of view, some of these techniques present more innovative elements than others, especially if compared with the current state of practices. On the one hand, SET and e-taxi concern inherent innovations in the structure of aircrafts and technological devices onboard. On the other hand, the use of tug vehicles required the use of the existing vehicles coordinating the tasks of the operators differently involved in taxiing manoeuvres.

The actors involved in taxiing operations, in all these cases, should be trained to use these new tools appropriately, presumably after the due upskilling and with specific license extensions. However, using SET and e-taxi techniques, the pilot remains the only actor in command for taxiing operations, with minimal consequences on traffic conditions. On the contrary, the introduction and /or increasing use of tug vehicle may considerably augment the number of vehicles circulating along taxiways. Additionally, the safe and secure execution of the operations will be jointly performed by two different categories of actors, with different know-how and liability regimes. This is the reason why, at present, the analysis of AEON devotes particular attention to the consequences related to the use of towing technique and the connected liability risks.

In light of the above, specific concerns were raised approaching the interactions between pilots and TDs. In this regard, the AEON concept relies on two assumptions. On the one hand, the information elaborated by the software is shared with TD and PIC throughout tablets or other digital devices, providing them symmetrical access to instructions provided by the TFM and the ATCO. On the other hand, the implementation of this solution presumes that pilots are trained to deal with AEON-equipped airport hubs to ensure they can profitably cooperate with TD in coupling and decoupling operations, as well as in towing phase.

Considering the issues that emerged approaching the legal regime of TD in AEON-managed taxiing operations, these assumptions need to be carefully analysed.

4.3.5.1 Basic rules of communication among TFM, ATCO, Pilot and TD

The original version of the AEON CONOPS assumes the communications among TFM, ACTO, Pilot and TD should be structured in two different blocks of tasks. First, there are communications between TFM and TD concerning the allocation of tug vehicles and the instructions for dispatching. On the other hand, there are communications among ATCO, PIC and TD for the correct performance of taxiing operations, including tasks-coordination for safe towing along taxiways.

Nonetheless, the description of tasks provided by the CONOPS presented just one of the possible formulations of the procedures at issue. For the sake of completeness, the liability analysis thus took into consideration even the other practices currently used in some airport hubs, according to insights provided by the stakeholders during the intermediate evaluation meeting.

As previously mentioned, the collected contributions illustrated how the pilot, in case of emergency during the towing phase, may need relevant and substantial support from the TD. Before an imminent risk of accident, this actor indeed could be in the most favourable position to intervene directly using local commands available on her/his vehicle. Having in mind these cases, it would be advisable to consider a potential change in communications priorities, addressing taxiing clearances not only to the pilot but even to the tug driver.

In the final simulations, the limitations of the validation context did not allow us to consider this insight. Tug drivers received instructions from the TFM for ground movements until the coupling points. After that, clearances for taxiing were provided to the pilot only, while the tug driver may access to this information being tune to the ATCO-PIC frequency. Since over the second Advisory Board meeting confirmed this sequence, this induced us to consider also the possible shortcomings related to a similar scenario.

As even explicated in the initial version of the CONOPS, in pushback operations, the ground crew supervisors must avoid interferences in communications that may have a negative impact on the primary completion of her/his staff’s task-responsibilities. Otherwise, tasks distribution would be materially frustrated by avoidable misleading communications, increasing liability risks for all the actors involved.

On the other hand, public and private standards and regulations, as well as customs, highlighted how it is further essential that all the operators involved in the procedures have a comprehensive understanding of the circumstances in which they work, and adequate situation awareness of the context considered as a whole. These interdependencies, indeed, allow all the actors involved to cover all possible abnormal and emergency circumstances effectively and efficiently.

In light of these assumptions, therefore, communication priorities should be addressed as a priority. On the one hand, the actors involved should not be exposed to redundancy risks. On the other hand, TD should have an adequate situation awareness, without incurring in communication fragmentation and misunderstanding. Bearing in mind the impact of these risk factors on the situation awareness of tug drivers and the performance of their own tasks, profitable and consistent adjustments are warmly suggested.

4.3.5.2 Basic rules for liability apportionment between TD and Pilot

As explained above, interactions between pilots and tug drivers are currently limited to push-back operations. The introduction of the AEON solution, however, may postulate a different scenario especially in emergency cases.

From a legal perspective, similar situations present critical junctures. Indeed, pilots and tug drivers are subjected to widely different liability regimes and, at least in principle, additional forms of collaboration of these two results are critical, even if limited to taxiing operations. In particular, following a comparative approach, these two positions present the differences described hereunder.

Tug drivers usually are not in an accountability position. Their liability regime is tailored to general negligence (see Figure 7): their professional standards are defined by their employment contract and their scope of liability is limited to their own task-responsibility. On the contrary, pilots are by definition in an accountability position and their duties and professional standards are regulated by several competing law sources.

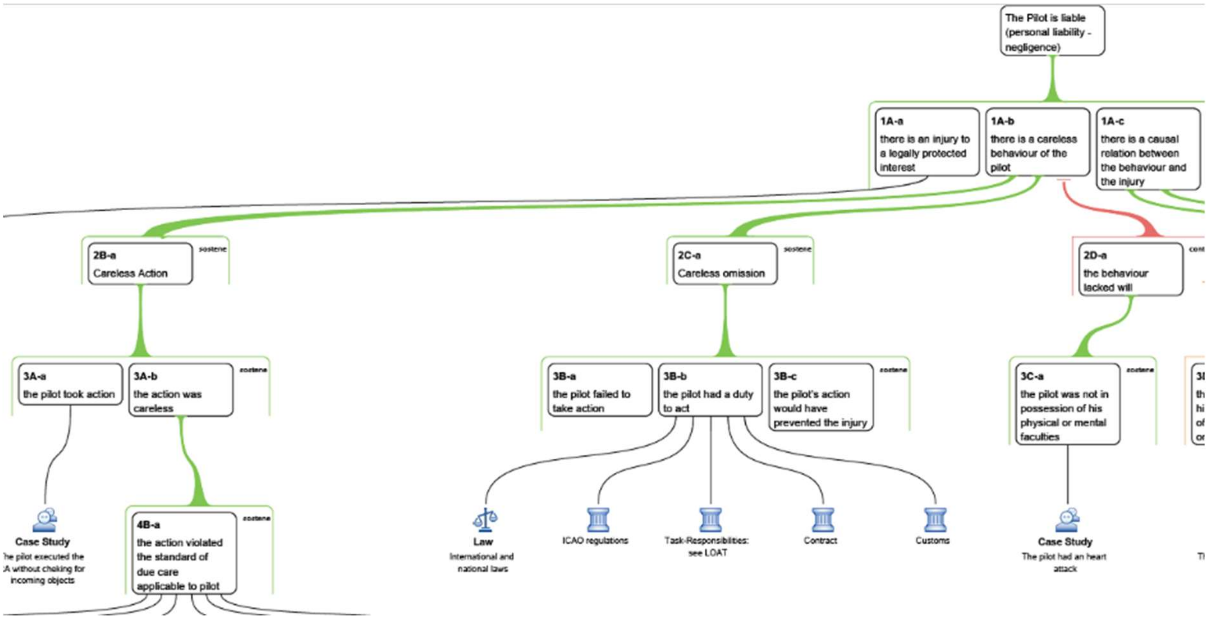

Figure 9. Map of pilot negligence

The map above describes the top level of the map for the assessment of the pilot's liability.

In particular, the pilot will be personally liable if the following conditions are jointly met: there is an injury to a legally protected interest; there is careless behaviour of the pilot; there is a causal correlation between the behaviour and the injury. Some exceptions or counterarguments may be advanced, for instance, in case the pilot's behaviour lacked will.

Careless behaviour may consist of a careless action or a careless omission.

The pilot's behaviour was careless when the pilot took action, and the action was careless. Carelessness is usually determined by assessing the action that violated the standard of due care applicable to pilots, that is the proper behaviour that a professional pilot would have been required to follow in the given situation. As previously mentioned, such expectations depend on the tasks assigned to the pilot, as well as on international and national law (such as codes of navigation) public and private standards and regulations, or even customs and caselaw.

The pilot's omission will be careless when the pilot failed to take action; the pilot had a duty to act, and the pilot's action would have prevented the injury. The contents of the duty to act will depend on the tasks assigned to the pilot, as well as on international and national law (such as codes of navigation) public and private standards and regulations, or even customs.

Evidently, the two regimes present substantially different professional standards and, implicitly, radically divergent education and training. In light of this, it is reasonable the introduction of AEON would require a serious review of the respective training of these two categories of actors, including testing and practice for critical scenarios.

4.3.5.3 Possible automation of TD's tasks and the impact on pilots' liability regime

An additional issue emerged over the application of the Legal Case to AEON concerns the possible automation of towing operations. This latter is a hypothesis already considered by the CONOPS (D1.1, p. 76, REQ-AEON.01-SPRINTEROP-TU01.0003). Indeed, the goal of some EU air-hubs on a medium-long term perspective is the full-automation of service vehicles. In the APTOs' view, in principle, this policy should include or be extended even to tug vehicles.

The above explained legal considerations (see Section 4.3.3.2) about the introduction of highly automated systems in taxiing operations already introduced these aspects and may be helpful to approach even this latter hypothetical scenario.

The attribution of liability, in this case, depends on the different characteristics of the highly automated system at issue and the role of the human actors involved. At a glance, the figures mainly impacted by this case would be the pilots, first and secondly ANSP, APTOs and manufacturers. Even in this case, if from an operative standpoint, the critical aspects concern the risks of human complacency, technical biases or failures and HMI design defects, the most relevant legal issues approaching the liability risks concern transparency, accessibility and explainability.

Pilots basically should deal with instructions provided by software that analyses information and scenarios autonomously, and they should adapt their behaviours consequently. In other words, human actors on the one hand should be in the position of relying on the information provided by the tool. However, to avoid complacency, they should also be able to challenge the results obtained and have significant insights into the logic followed by the algorithms implemented by the software. A critical factor concerns human inhibitions to make divergent decisions from the one suggested by the tool, and the related legal consequences for actions or omissions motivated by uneasy detectable biases and/or complacency.

In particular, it is noteworthy that automation, in this case, would not be limited to decision-making but impact the material execution of operations. Consequently, the design and implementation of tools and techniques adopted for coupling and decoupling procedures, as well as self-driving tug vehicles, should be inspired by the human-in-the-loop principle, allowing timely human interventions by pilots and ground handlers in case of adverse contingencies or malfunctioning.

If the tools and vehicles adopted to implement this system will not meet all organizational and design requirements generally prescribed to producers and organizations these latter may be considerably exposed to organizational and product liability risks.

4.3.6 Organizations and product liability issues related to automation

Solutions like AEON implicitly involve the redefinition and automation of some tasks. All these design issues concerning roles, tasks and procedures required a meticulous and prudent intervention by the organizations implicated. In these cases, indeed, innovation is a vertical process. APTOs, AOs and airlines, and ANSPs thus have the burden to ensure the safe and secure development and implementation of new protocols. This commitment includes all aspects related to the quality of the technologies adopted, the fair design of the procedures on use, and adequate training and personnel upskilling.

On these grounds, the liability analysis of AEON also considered the legal issues related to the implementation and operational phases of AEON as a whole. Beyond the individual perspective, the following paragraphs aim to provide some context-based insights based on the organizational issues that may increase the risks of accidents. For the sake of clarity, organizations and product liability will be approached separately.

4.3.6.1 Organizations liability

Generally, organizations can be liable in two different situations. On the one hand, the organization, as an employer, may be responsible for the behaviour of its employees. In this case, the employee is the subject materially liable and answers for primary liability. Instead, the organizations charged with the legal consequences of this behaviour and thus answers for secondary liability or vicarious liability. However, organizations can be subject even to another form of primary liability, now related to their own business activity and the potential negative consequences for third parties. This latter is usually identified as enterprise liability.

These two forms of liability need scrupulous attention when organizations consider or decide to adopt and implement highly automated solutions. Indeed, opting for these innovative strategies, the organizations (for the purpose of this report, ANSPs and APTOs), on the one hand, are responsible for the behaviour of their employees in the interactions with the new tools. In this connection, they have to ensure adequate training for familiarizing with and using these new technologies, ensuring the efficient and safe performance of usual tasks. On the other hand, they are further responsible for all the organizational aspects of these innovations, choosing only those products or solutions adequate for their operative purposes and tasks and reviewing all the internal policies and procedures impacted by the innovation.

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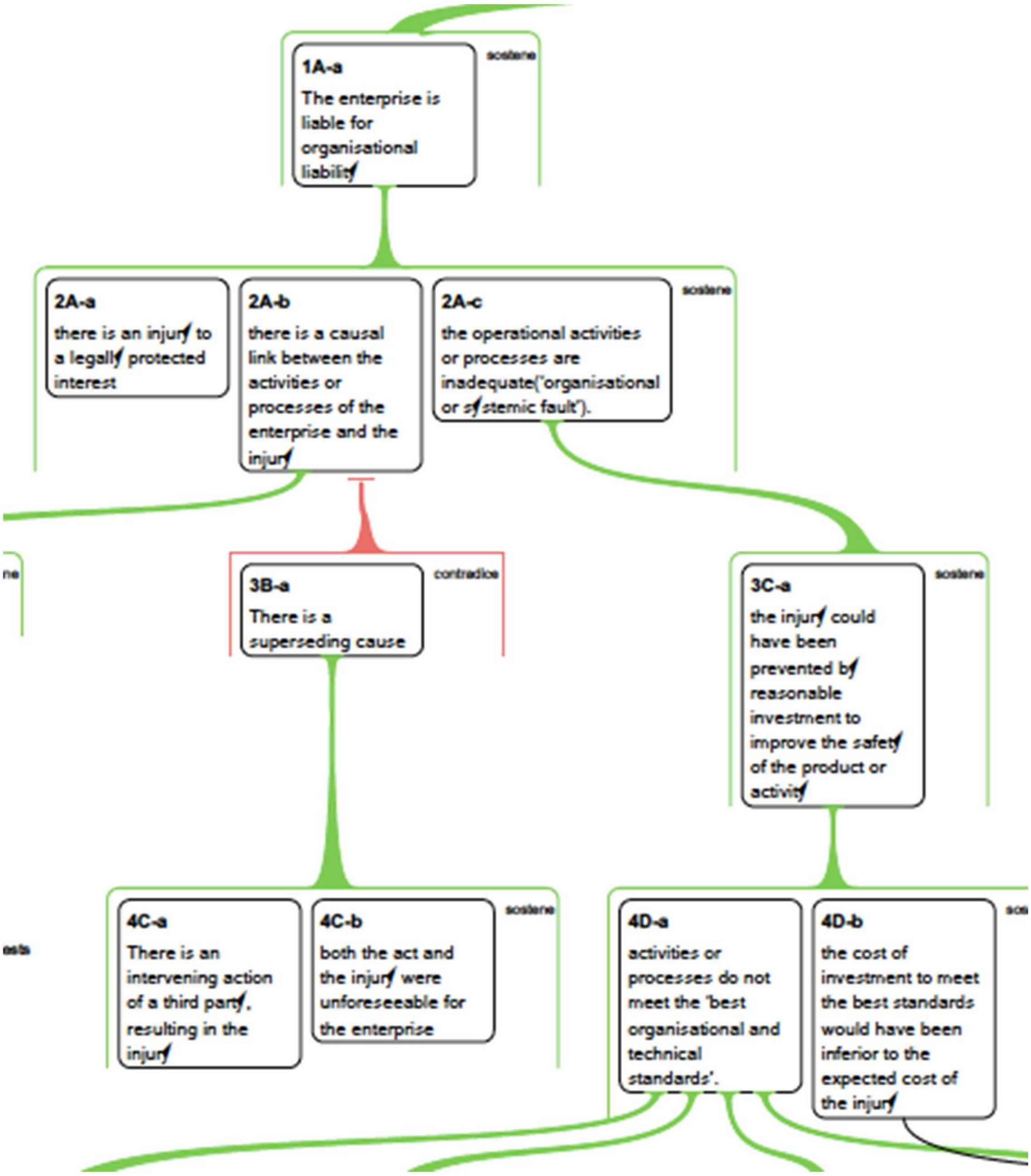

Figure 10. Map of enterprise liability

The map above is an extract of an enterprise liability map that focuses on organizations' liability and may provide helpful support in a better understanding of the issues at stake. Organizations' liability is one of the main grounds of enterprise liability, with vicarious liability, and may include other specific forms of liability (e.g., product liability).

In general, an enterprise will be liable for organizational liability if the following conditions are jointly met: there is an injury to a legally protected interest; there is a causal link between the activities or processes of the enterprise and the injury (even when they cannot be traced to any individual wrongdoing), and the operational activities or processes are inadequate ('organizational or systemic fault').

The automation of tasks basically involves the development and/or the deployment of a technology that can integrate or replace the human agency. Beyond efficiency considerations, the tools adopted must satisfy common security and safety standards and ensure that different humans involved in the procedures may be able to monitoring the activities automatically performed by machines and promptly and efficiently intervene in the process when needed.

From a legal perspective, these concurrent requirements can be approached in light of four different criteria:

- the quality of products, intended as the appropriateness and suitability of the design of technology developed/adopted for the intended uses;
- the quality of the procedures, intended as the proper and adequate review, amendment and/or renewal of current standards and protocols in light of the changes introduced by the new solutions;
- the quality of the implementation, intended as all the active and proactive measures adopted or to be adopted for a secure and safe implementation of the solutions
- the quality of the investment, intended as the delivery of funds for the execution of the project and the secure, safe and efficient use of the new solution over time.

The careful assessment of all these elements, indeed, contributes to ensuring activities or processes constantly meet the 'best organisational and technical standards', mitigating the liability risks exposure of the organizations involved. The measures may include (but are not limited to) initial and periodic training sessions, initial and periodic audits on the correct functioning of systems and procedures, and initial and cyclic assessment of the technological layout of the procedures even in light of the innovation meanwhile occurred.

Considering the specific case of AEON implementation, it is advisable to pay particular attention even to per-automation conditions related to the airports and their related structures. This would be consistent with the requirements currently provided by the ICAO Annex 2 regarding the frame and layout of taxiways. Reading the recommendation, the mentioned Annex indeed prescribes that "such roads should be direct, simple and where practicable, designed to avoid traffic conflicts" (ibid., §2.14.1). On this ground, the organisations involved – APTOs, first – should take into account the layout of their taxiway and service roads to meet the rationale of this requirement. Indeed, strategic and organisational decisions concerning these aspects represent a material pre-condition to introduce and ensure the 'best organisational and technical standards'.

4.3.6.2 Product liability: the impact of automation on design and warning requirements

The state of the art of automation furtherly calls for the debate of the role of manufacturers and producers in the development and implementation of new technological solutions.

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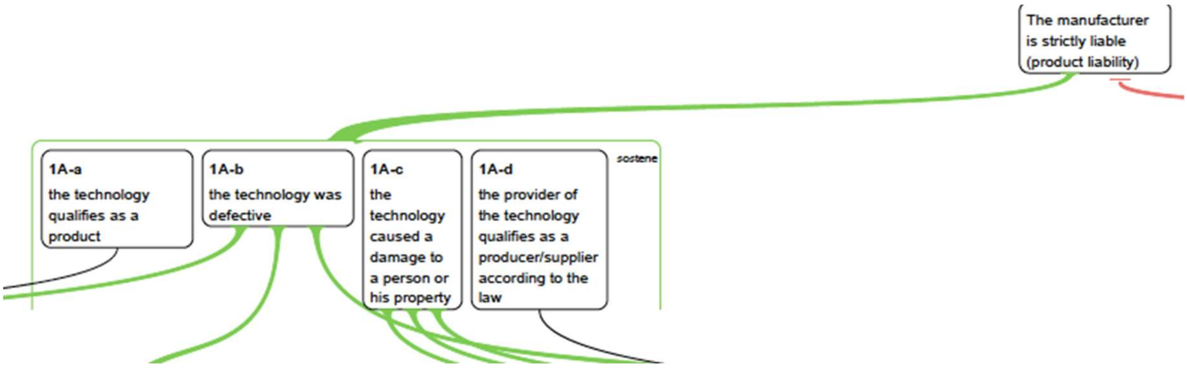

Figure 11. Map of product liability (top level)

The map above describes the top level of the map for the assessment of product liability. The map shows that this liability hypothesis ("the manufacturer is strictly liable under product liability") can be confirmed if the following conditions are jointly satisfied: the technology counts as a product, it is defective, it causes damage and its manufacturer qualifies as a producer. Under general principles, three alternative conditions for a product's defectiveness are commonly distinguished: a design defect, a manufacturing defect, and a warning defect.

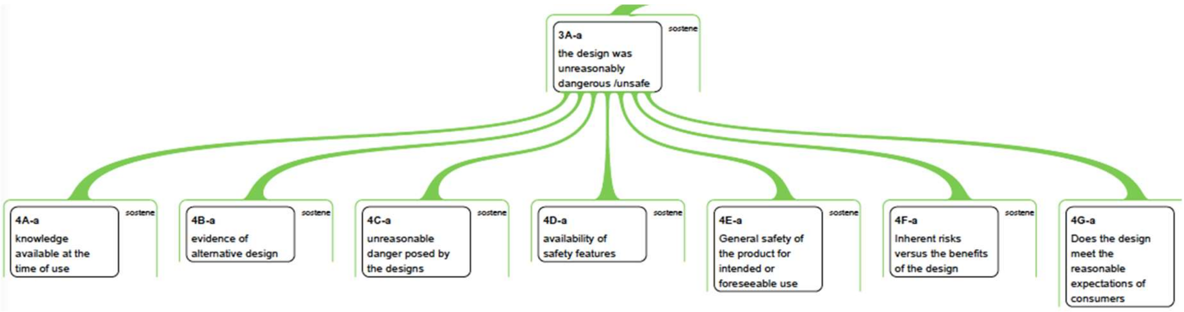

Figure 12. Map of product liability

The map above is an extract of the product liability map focused on design defects. In light of this, the first relevant product liability risk exposure related to design may concerns different and alternative scenarios. Special attention should be paid to availability of safety features; general safety of the product for intended or foreseeable use; inherent risks versus the benefits of the design; and if the design meet consumers and users' reasonable expectations.

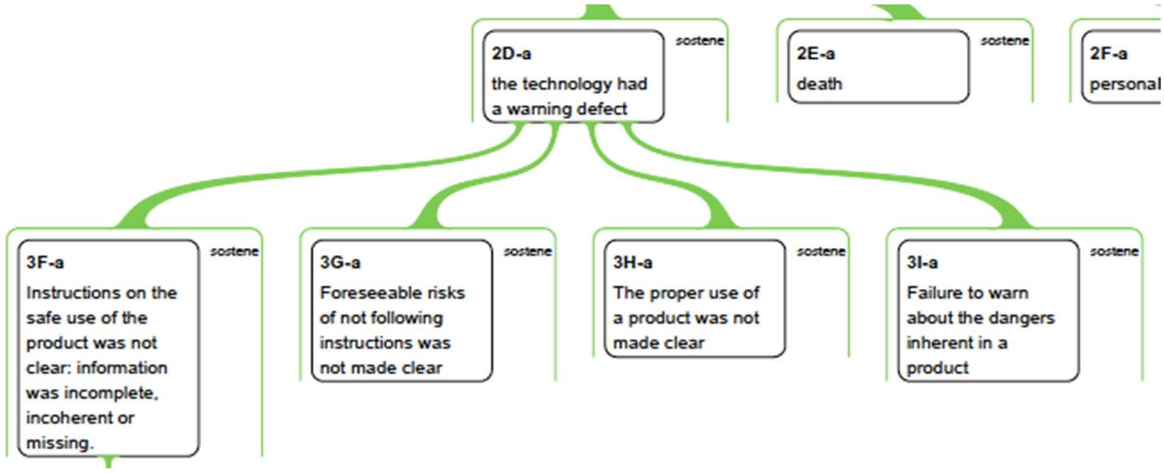

Figure 13. Map of product liability (warning defects)

Eventually, this last map (above) introduces the potential issues related to product liability related to warning defects. These latter, in particular, are connected with the problems related to complacency. In this regard, the producers should guarantee clear, complete, coherent and comprehensive instructions on the safe use of the product clear; a clear description of foreseeable risks related to not following instructions; specific directions about the proper use of the system and adequate warnings about the dangers and limitations inherent in this latter.

If all these requirements are not adequately satisfied, producers and organizations may be considerably exposed to liability risks.

4.4 Actor-based liability analysis

From the analysis proposed in section 4.3, it is possible to derive a high-level view of the net changes in liability that derive from the potential use of the AEON solution. It is noteworthy that the following considerations take into account all the emerged elements, going even beyond the initial understanding of the CONOPS.

In this section, therefore, the report will identify the possible variations of liability regimes that derive from the use of AEON for the various actors involved following the sequences of interactions defined by the initial version of the CONOPS.

4.4.1.1 APTOs and AOs

Generally, APTOs and AOs will see a modest redefinition of their liability regime. Individually considered, from a civil law perspective, they will continue to be exposed to moderate risks, usually economically supported by the insurance coverage required by law. Analogous considerations are valid from the criminal liability perspective. In this regard, the exposure should be considered modest, even according to the current state of the art in most EU national legislation about the criminal liability of enterprises and organizations.

Furtherly, depending on the economic model adopted for the implementation of AEON, these subjects will also be vicariously liable for the behaviour of their employees. The working contractual position of the TFM, in particular, needs to be taken into careful consideration, both in terms of secondary and primary liability.

This situation, however, could be severely impacted by the implementation of the AEON solution assuming the use of highly automated systems for planning and dispatching, APTOs should be considerably exposed to organizational liability risks. In particular, they will be asked to answer about the choice of the best technologies available for their purposes; consequent organizational and procedural replanning and adequate training of the employees and professionals involved in the innovation process.

4.4.1.2 TFM

A clear definition of the TFM's liability regime depends on the economic model adopted as well as the factual and contractual understanding of her/his task-responsibility.

In this connection, if the TFM is compared and assimilated to a dispatcher, it is reasonable to assume that s/he will be subject to a generic professional civil and criminal liability regime. S/he will be considered responsible and liable for her/his tasks only, excluding any accountability duty.

On the contrary, if intended as a proactive and supportive figure to the ACTOs, the TFM should be trained as an ATCO and should be subject to an analogous civil and criminal liability regime, including some accountability duties related to the instructions provided to tug drivers.

4.4.1.3 ANSP

Since the implementation of the AEON solution assumes the use of automated systems for planning and dispatching, ANSPs should be exposed to organizational liability risks. In particular, they will be asked to answer about the choice of the best technologies available for their purposes; consequent organizational and procedural replanning and adequate training of the employees and professionals involved in the innovation process. Considering the accountability position of ATCOs, all these elements should be carefully taken into account ex-ante and ex-post, ensuring adequate safety and liability impact assessment from the early stage of the implementation and, periodically, over the ongoing operations.

4.4.1.4 ATCO

About the ATCO, the liability regime of this latter is interdependent with the outline decided for the TFM.

If the TFM is intended as a dispatcher, the ATCO civil and criminal liability risks exposure is highly impacted. Since TFM would be responsible for her/his tasks performance only, the ACTO, in light of her/his accountability position, may be secondarily liable for the careless behaviour of the TFM.

If instead, the TFM aims to be a proactive and supportive figure the situation would change. Since the two actors would have comparable training and situation awareness, their civil and criminal liability outlines could be considered equivalent and concurrent, since both should be accountable and responsible for their mutual interactions. This second option would ensure a better and more balanced apportionment of liabilities between these actors.

Eventually, it has to be noted that the introduction of highly automated solutions would have a significant impact on ATCO's liability risk exposure. In particular, if the figure of the TFM would be replaced with an algorithm, this latter should have adequate design and warnings to ensure the ATCO will always be effective in the decisional and operative loop. Particular attention should be paid to the adaptation of operative manuals for cases of divergent human decisions from the suggestions proposed by autonomous systems.

4.4.1.5 Tug driver

In principle, if approached according to the initial version of the CONOPS, the tug driver is not sensibly impacted by the introduction of the AEON solution. Civil and criminal liability exposure of this actor, indeed, should remain unvaried as currently regulated by standards protocols.

However, considering the role this should play in case of emergency, there could be some issues related to communications priorities and interactions among TFM, ATCO and tug drivers during the taxiing operations. These latter, indeed, may severely impact primary civil and criminal liability risk exposure for tug drivers and secondary liability for the other subjects involved.

These potential shortcomings should be addressed with dedicated policies and specific training.

4.4.1.6 Pilot

As anticipated, the introduction of the AEON solution, in general, may have a limited impact on the liability regime of the pilot. Civil and criminal liability exposure of this actor, indeed, should remain unvaried as currently regulated by standards protocols.

Nonetheless, the extended use of towing for the whole duration of taxiing operations implies that pilots are well trained and familiar with the related standards and procedures. In particular, considering their accountability position in the performance of all taxiing connected operations, they have to be proficient in all their own tasks and be able of cooperating with all the other actors involved.

4.5 Summary of the Liability Assessment Results

The following Table aims to provide an overall picture of the impact the AEON concept of operation will have on liability risk exposure of the involved actors.

Validation objective	Detailed validation objective	Criteria	Results
VO7 | LIABILITY			
To validate that the liability risks associated to the AEON solution are acceptable for actors and stakeholders	1 The AEON solution is compliant with current regulatory framework	1.1 The AEON solution is compliant with current regulatory framework	Yes. In principle, it could be compliant
	2 Liability risks are acceptable for the concerned actors and stakeholders	2.1 Liability risks for operators are considered	Yes

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		2.2 Liability risks for organisations are considered	Yes
		2.3 Liability risks for manufacturers are considered	Yes
	3 Liability risks mitigations are considered	3.1 Means to mitigate the liability risks of the operators are considered (if needed)	Yes, according to the current maturity level of the CONOPS
		3.2 Means to mitigate the liability risks of the organisation are considered (if needed)	Yes, according to the current maturity level of the CONOPS
		3.3 Means to mitigate the liability risks of the manufacturers are considered (if needed)	Yes, according to the current maturity level of the CONOPS

Table 12. Summary of the Liability Assessment Results

4.6 Recommendations

The application of the Legal Case method to AEON leads to drafting some recommendations for the next steps of design, development, implementation, and testing of this new solution. It is important to underline that the conclusions reported hereafter are based on the analysis conducted by the Deep Blue team starting from the understanding of the concept of operations as it is intended nowadays. This understanding is derived from the CONOPS (D1.1), the intermediate evaluation meetings and the results obtained in final validation simulations. Any change in the concept of operations could lead to different liability allocations and therefore to different conclusions. In the following, most of our recommendations to tackle and mitigate the liability risks associated with the introduction of AEON are in the direction of refining and validating its concept of operations, following the track of collaboration among the different units/teams represented during the interactive workshops.

In light of the above, from a legal and liability standpoint, it is advisable to consider the implementation of at least these 3 main sets of recommendations.

4.6.1 Recommendations concerning the design of AEON solution

- The first recommendation is related to the **linguistic formulation of the new tasks** outlined in the workflow.

Reading the documents that identified and described tasks, we noted that the attention usually focuses on what the actors can (i.e., is able to) do interacting with the software and interfaces. This approach, however, once performing a liability analysis of the concept, risks being misleading.

From a legal perspective, the actors involved in the procedures may have a positive legal status – a right or a prerogative to obtain something from someone else; a negative legal status – a duty to do or provide something to someone else; and a neutral legal position, when they are free to do or not to do something according to their preferences and/or material possibilities.

Against this background, what an actor can or cannot do interacting with a tool is relevant for addressing the problems related to the design quality of this latter and the possible product liability issues. Nonetheless, to properly approach primary, individual liability concerns, and secondary, individual or organisational vicarious liability problems, we need a more careful formulation of the new tasks, **highlighting the prescriptive and deontic value of the propositions**.

From a practical perspective, for instance, task descriptions should include a statement reporting what the operator can materially do with the device/technology at issue (i.e., what the technology allows to do) using a phrase structure like “the subject can + action” or “the system allows + alternatives”. This first outline should be followed by a prescriptive statement specifying what the operator has to do or avoid from a safety and liability standpoint. In this case, an advisable phrase structure may be “the subject shall + action” and “the subject is responsible for doing/avoiding + event”.

- Secondly, the design and the implementation of the solution need to pay specific attention to the **symmetrical information sharing and priorities of communication** among the different actors involved.

As mentioned above, according to the CONOPS, all the subjects involved in the new protocols introduced with AEON should have a proper device and a dedicated interface to obtain all the information needed to perform their tasks. However, the limitations experienced during the simulations demonstrated how – at least at present – this information could be shared via radio, with the only exception of TFM and ATCO which already have their dashboards.

Radio communications could be a profitable solution, especially in these early stages of testing. Nonetheless, to ensure all the actors always have adequate situation awareness and can access the information they need, different alternatives are warmly suggested. In particular, the solution introduced by the CONOPS, where all the actors have their own device and interface for real-time updates about taxiing operations, should be pursued with determination.

- A third general recommendation, eventually, considers **the impact of automation on standards and procedures** according to the initial version of the CONOPS as well as its possible future development.

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As anticipated, the introduction of new levels of automation requires careful impact assessments by the organizations, both on the individual liability risks of the single actors involved and on the final process considered as a whole.

In this regard, it is warmly recommended to test the current concept of AEON in peak traffic conditions before considering any improvement in the automation of tasks. In addition, in a long-term perspective, higher levels of automation always have to guarantee the human-in-loop principle, ensuring effective and promptly monitoring and intervention capacity for the human agents involved.

4.6.2 Recommendations concerning the internal policy strategy for the implementation of AEON solution

- The first set of recommendations concerns the **criteria for a fair qualification of the TFM**.

As explained above, in designing the figure of the TFM, the entitled organisations (e.g., APTOs, AOs, ANSPs) should consider the individual abilities possessed by the future candidate, as well as the contextual conditions where s/he will be called to operate. The two hypotheses considered in this report – namely, the TFM as a dispatcher or a figure equated to an ATCO – in principle are both valid. Nonetheless, each of them involves significant differences in the liability regime of the TFM and the other actors involved, especially the ATCO.

In light of this, considering the two, it is advisable to include within the decision-making criteria: the complexity of the context where the operator is called to intervene (the whole airport, as well as the single sectors), the complexity of the operations performed in that context in light of the experiences and future traffic conditions, the sources of risks previously encountered in that context, including (but not limiting) environmental and meteorological conditions. The liability regime of the selected figure and the liability risk exposure of this latter and the other collaborating with it, should be tested in light of all these factors.

- The second set of recommendations needs to focus on **training and licensing policies**.

Since the early stage of the implementation of AEON, all the actors involved in planning and execution of operations have to receive adequate training about the rationale, functioning and limitations of the software and dashboard. Training needs to be calibrated and periodically updated on the maturity level of the technologies involved, with periodic testing on the impact of these latter on individual tasks performance and the efficiency and safety of operations.

In principle, training and licensing policies for AOs and airlines, ground handling companies and TFM can vary according to the specific organisational and economic strategies made at the local level. However, it is warmly recommended to elaborate a unitary set of guidelines for training of ATCOs and pilots, even in light of their well-established accountability positions.

Organisations which decide to implement solutions like AEON should devote particular attention to the choice of the technologies adopted for the design of protocols and procedures, including adequate training and licensing extensions. Where necessary, APTOs and ANSPs should consider introducing new licences, according to the new skills required to the involved operators *(e.g.,* TFM*).*

- Eventually, there are some general recommendations about the **use of structures, with a particular emphasis on the use of taxiways and service roads**.

AEON solution will increase the number of circulating vehicles along these paths. This boost will considerably impact on ground traffic conditions and, as a consequence, the rise of incidents and accidents risks.

The recommendations contained in Annex 11 (Air Traffic Control Services, Flights Information Services, and Alerting Services) about taxiways prescribe that “such roads should be direct, simple and where practicable, designed to avoid traffic conflicts” (ibid., §2.14.1). In light of this, it is advisable to expand the rationale of this recommendation to service roads and define local policy documents for the use of taxiways and service roads in the line with these prescriptions and the operative needs related to the implementation of AEON.

4.6.3 Recommendations concerning the contractual regulation of the relationships among the different actors

The last set of recommendations concerns contractual relationships among the different actors. In this regard, the two figures that, more than others, need a careful contractual definition of their roles and duties are the TFM and TD.

Firstly, considering the position of the TFM, this actor could be an employee of the APTO, ANSPs, airlines or ground handling company, according to the economic model applied for AEON implementation. These alternatives suggest paying particular attention to the exact definition of the professional status of this manager since the contract of employment will be the primary legal basis of her/his legal and liability regime.

In light of this, the contractual regulation should punctually define the licences required for performing this role, bearing in mind the consequences of this qualification on the tasks and liability risks of the other subjects involved.

In addition, where AEON will be implemented as a context-limited solution (e.g., only in some sectors of the airport or as an in-house service autonomously organised and provided by airlines or ground handling companies) the contractual definition of tasks should include the priorities and coordination rules with ATCOs manual.

Analogous considerations are valid in approaching the contractual situation of the TD. Since the contract of employment will be the primary legal bases of her/his legal and liability regime, tasks definition and distributions should be punctually defined by the contract, including licences and extensions required for performing this role.

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5 Conclusions and way forwards

The rich set of results presented in previous chapters of this document proves the effectiveness and suitability of the iterative and multidimensional validation approach adopted in AEON. In particular, the proposed approach confirmed to be suitable to the current level of the maturity of the envisaged solution, and effective to proactively feed the design and refinement of its operational concept and associated tools towards further stages of the project, and possibly foster the progression of the research in this area through the SESAR innovation pipeline.

Methodological considerations

From the methodological point of view, the addition of a novel KPA dedicated to the analysis of the possible liability impact of the AEON solution for the different stakeholders involved proved to be effective. The introduction of the liability by design approach at this stage of the research allowed the early identification of possible issues and blocking points that at this stage could be quite easily mitigated by means of different choices at design level.

In addition, the combination of this approach with the more traditional and standardised user-centred design and validation approach entailed in the SESAR HP assessment process allowed to highlight the complementarity of the two approaches.

The results concerning the suitability of the new TFM role introduced by AEON, offered a valid and explicative example of the advantages of combining the two approaches in a common user-centred design and validation perspective.

Need for an overall revision of the TFM role and associated working methods, tasks and tools

From the study carried out with the end users it was evident that the new key role of the AEON proposed solution, namely the TFM, had been defined in a too vague way in the initial operational concept. This gave the ATCOs involved in the study a certain level of flexibility on how to perceive and play this role during the study.

As extensively reported in previous chapters, two main working styles emerged, which were also quite divergent from one another. On the one hand, we had the participants who tended to perceive and interpret the TFM role in analogy to a flight dispatcher, while, on the other hand, we had those who tended to perceive and interpret it as a simile-ATCO. The main difference that derives from the application of these two different styles is that in the first case they tended to play a quite passive role, thus avoiding changing the tug allocation to aircraft, while, in the second case, they tended to play a much more active role with the purpose to optimise the tug-aircraft allocation.

We cannot say how much this phenomenon was influenced by and due to the fact that the algorithms designed by the AEON consortium for tug allocation and path planning were not used during the final validation session, and/or by different attitudes to trust in the system characterising the participants involved. However, what is important to notice is that these two divergent behaviours highlighted a need for a clearer and more precise definition of this role and of the associated working methods and tasks, in order to reduce the variability of the human performance while playing the role.

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In order to provide insights for the refinement of this role, the two styles were duly analysed from both the perspectives considered in this report, namely HP and liability. Interestingly, the two approaches came to the same conclusion, even if anchoring to different argumentations of the specific area of investigation. The conclusion in both cases was that, although both styles could be applicable (i.e., none of the two implied blocking issues and/or showstoppers), the first one (i.e., TFM as a flight dispatcher) could be more problematic and riskier to adopt in daily operations than the second one (i.e., TFM as a simile-ATCO).

The arguments used by the two approaches to come to this conclusion were inevitably different but strictly related. In a nutshell, they showed that the first option (i.e., TFM as a flight dispatcher), although apparently might be perceived as simpler and more straightforward to adopt than the second one (i.e., TFM as a simile-ATCO), in reality could be risky for the Ground ATCO. From the HP perspective, this could be due to the different background of the two roles that may imply possible problems of collaboration, effective support and mutual and shared situational awareness. On the same page, from the liability perspective, the different qualifications and backgrounds may aggravate the accountability position of Ground ATCO. S/he would see her/his general duty to care further extended to the tasks previously performed by the TFM and would include an implicit duty to check the allocations defined by this latter and approve them as suitable to the current traffic scenario. In other words, the choice of assigning the role of TFM to an actor not configured as an ATCO may imply more serious consequences in terms of liability exposure for the ground ATCO who receives the tug allocation and shall apply it, and for those who collaborate with him/her, rather than for the TFM him/herself.

From the methodological perspective, what is interesting to notice is that the two set of results were synergic and reinforced each other, thus bringing to the common recommendation to consider the TFM as a simile-ATCO role in future stages of the project, rather than as a kind of flight dispatcher. This in turn implies a need for further detailing the working methods and tasks of this role in this perspective, as well as to opportunely consider this nature of the role while redesign the HMI of the various supporting tools and the communication means and channel used with the other concerned actors. Additionally, some initial considerations about the implications in terms of new ATCO skills, licencing and staffing can be formulated in order to take into account the introduction of this simile-ATCO role.

Need for more detailed design of communication flows and associated channels and tools

The results related to the TFM just discussed show the fundamental importance of a suitable role definition in the systemic design of an operational concept. The identification of the concerned roles and the prospective analysis of the possible impact of the proposed solution on them are at the bottom of the operational concept design. Indeed, all the other components of the concept of operation are linked with and somehow also dependent on them, namely working methods and tasks, human interaction with the proposed system, computer supported cooperative activities among different actors, transitional factors. This means that unsuitable role definitions may seriously compromise the success of the proposed operational concept, particularly if discovered when the operational concept and associated tools are already advanced and quite mature.

In the AEON project validation assessment, we were lucky enough to discover that the roles identified as affected by the proposed solution are actually those taken into consideration. In particular, the study carried out with the end users confirmed the complexity of the concept of operations and the need to consider the multiple actors involved in the overall process. From what emerged from the study, we can confirm that the roles were suitably identified and defined at this stage of the project, but for the case of the TFM already known, and that the overall flow of activity (represented also in the project concept image) had been appropriately designed.

Nevertheless, the design of the way such roles cooperate and in particular communicate appeared as one of the weak components of the current version of the operational concept, thus claiming for more attention in future stages of the design process. In particular, both the HP assessment and the liability analysis highlighted the need for a more detailed definition of the communication flows among the different actors and of the associated tools used to mediate the communication. The reference to the communication tools concern both tools that already exist (i.e., the R/T) and the new ones introduced by the AEON project (i.e., the communication mediated by the Ground ATCO HMI via a dedicated message box or the information provision on the aircraft labels). In both cases, the choice and the design of the communication tools to be used and the definition of how to use them shall take into account the expected communication flow and be suitable to it. Various examples of communication flows and tools that would require a more detailed design in later stages of the project were collected during the study and are reported in both sections 3 and 4. They are not reported here in order to avoid to put emphasis on them as the main purpose of presenting the topic in the conclusions is exactly to stress the message that actually a systemic reconsideration and redesign of the overall communication flows and of the associated channels and tools is needed in order to allow the concept to reach a higher level of maturity.

What operational scenario for towing vehicles: taxiways or service roads?

The iterative nature of the validation process allowed to have multiple moments in which the AEON consortium met the end users and the stakeholders possibly affected by the proposed solution and collected their feedback and inputs. As expected, this iterative and incremental approach allowed to progress in the operational concept design during the project and to reach the final validation session with a concept of operation and a set of tools whose design had already taken into account the preliminary inputs and feedback of users and stakeholders.

In addition to that, the iterative validation approach adopted allowed the AEON Consortium to collect suggestions for considering alternative ways of designing the operational concept or some components of it, that could not be embraced tout court at this stage of the project, but were potentially relevant and thus were used to formulate and explore alternative hypotheses of design. This is what happened during the intermediate validation, when experts from Schiphol airport suggested the idea, derived from some previous research activities in which they were involved, to use dedicated service roads instead of taxiways for tug vehicles, when those are not coupled with aircraft. This option had not been taken into account by AEON before and there was no time to implement it before the final validation session as this would have required not only to update the platform but also, and most demandingly, the design of suitable service roads. However, it was interesting, and it was then decided to explore it as alternative to what foreseen in the operational concept in both the HP assessment and the liability analysis. Interestingly what emerged from the study is that the strategy suggested by AEON (namely, the use of taxiways by uncoupled tug vehicles) may be problematic and introduce issues from both the HP and liability perspectives taken into account. From the HP perspective, it may affect the ground ATCO workload and the attention required to him/her due to the increase of the number of vehicles on the taxiways and the variability of their performances (i.e., aircraft taxiing using different techniques and decoupled tug vehicles). From the liability perspective this would require a need to clearly justify this choice with respect to the recommendations contained in Annex 11 (Air Traffic Control Services, Flights Information Services, and Alerting Services) about taxiways that prescribe that “such roads should be direct, simple and where practicable, designed to avoid traffic conflicts”. This is another valuable example of how the combination of the two complementary approached may be beneficial to allow the project to get a richer and more robust set of results. In this case, we cannot conclude that service road shall be preferable to the use of taxiways, of course, because the effect of the first ones on the operations and on human performances were not tested. However, from the study and most important from the combined results of the two analyses, we may conclude that the option of using service roads shall be explored in further stages of the research in this area.

The impact of the introduction of higher levels of automation is not in the scope of this validation activity and shall eventually be considered in further research initiatives

Finally, a further topic emerged during the validation process that is worth being reported in these conclusions concern the future evolution of the proposed solution and how to consider it in the framework of the current validation process and more generally of the project. In several occasions during the validation process, the introduction of higher levels of automation was mentioned as a possible evolution of the proposed solution. It was done in relation to tug vehicles, that in the AEON concept are considered managed by dedicated and opportunely skilled tug driver, while in the future could be autonomous or more autonomous. It was done also in relation to the role of the TFM, that in the future may be supported or even replaced by algorithms of artificial intelligence. Even if prospectively thinking at these possible future directions and at their impact on the operations could be attractive, it is evident that this is not part of the research carried out by the project and the results presented in the current document shall primarily focus on the validation of the concept of operations that has been defined by AEON and of the different tests carried out with the purpose of supporting the consolidation of the concept of operations itself.

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