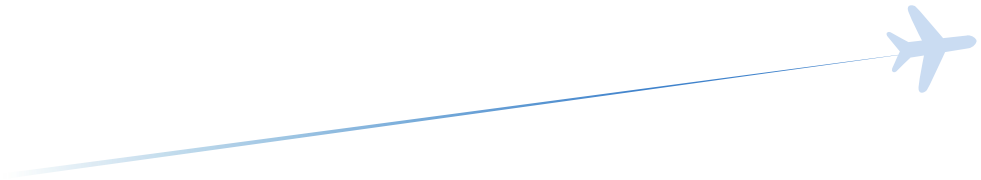
EXPLORATORY RESEARCH



Solution Assessment Plan

Deliverable ID:	**D5.1**
Dissemination Level:	**PU**
Project Acronym:	**AEON**
Grant:	**892869**
Call:	**H2020-SESAR-2019-2**
Topic:	**Innovation in Airport Operation**
Consortium Coordinator:	**ENAC**
Edition date:	**31 January 2022**
Edition:	**00.01.00**
Template Edition:	**02.00.02**

Founding Members

EUROPEAN UNION EUROCONTROL

SESAR JOINT UNDERTAKING

AEON

ADVANCED ENGINE-OFF NAVIGATION

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

Abstract

AEON aims at fostering the usage of environmentally friendly ground operations techniques such as autonomous (i.e., e-taxi), non-autonomous (i.e., TaxiBots) or Single Engine Taxiing (SET).

The present document presents the Solution Assessment Plan of the project. Its purpose is to describe the overall validation approach defined by the AEON Consortium to validate the AEON Concept of Operations and further consolidate it based on the results of the validation activities.

The validation approach adopted is iterative and involves internal and external stakeholders and experts in the ATC domain, since the earliest phases of design and validation process of the AEON concept of operations and tools. The validation approach is based on three validation sessions, called respectively initial, intermediate, and final, in which the AON concept of operations and tools have different levels of maturity (from early V1 to a fully complete V1).

Besides the overall approach, the present deliverable describes the research questions, hypothesis, objectives, and organisation of the three evaluation phases, as well as the structure and planning of the validation activities to assess the impact of the AEON solution on the key areas identified as relevant for the project, namely Human Performance, Safety, Cost, Capacity, Efficiency, Environment, and Liability.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose and scope of this document

This document presents the AEON Validation Plan, detailing the objectives, the relevant stakeholders, the validation requirements and experimental approach, and the planned validation activities of the project. This plan has been generated taking into account SESAR recommendations [1][8][9], the European Operational Concept Validation Methodology (E-OCVM) [2], and the SESAR Human Performance Assessment Process V1 to V3- including VLDs [3].

Developed in WP5, under Task T5.1, the Validation Plan is the reference document that will be used to organize and manage the evaluation sessions (preliminary, intermediate and final) planned by the AEON Consortium to test and validate the AEON concept of operations developed in WP1, specifically in D1.1 – Concept of Operations Initial [6].

The Solution assessment plan presented in this document, along with the requirements of the human performance (HP), safety, cost-benefit, capacity, environmental impact and liability assessment, set the strategy the Consortium will follow to evaluate the AEON solution.

The deliverable and the validation activities described are also strictly linked with the work done in:

- WP2, that designed and produced the AEON algorithms
- WP3, that defined the relevant use cases to be tested and the HMI prototypes, and
- WP4, that provided the simulation platform used in the final validation session and integrated algorithms and prototypes.

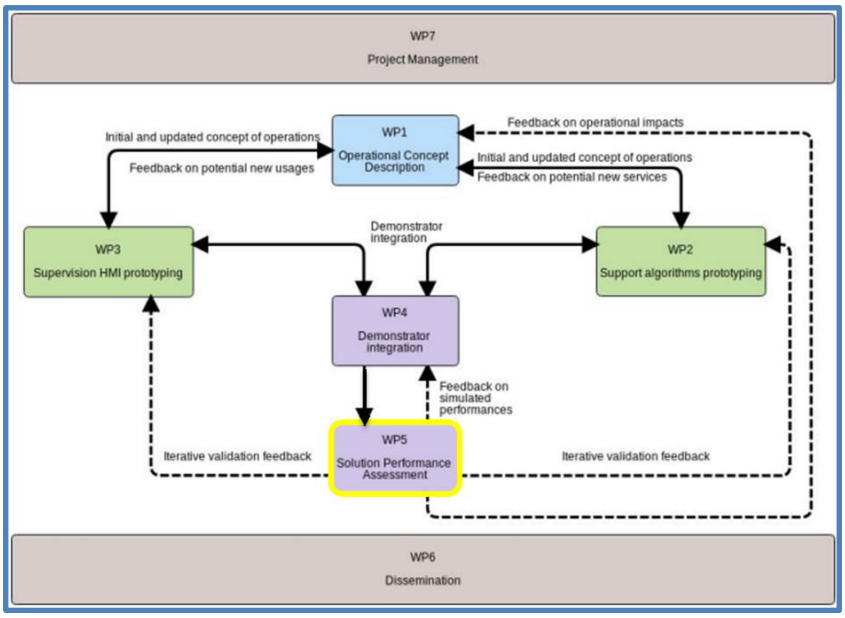


Figure 1. Validation in the AEON overall framework

1.2 Related documents

This deliverable takes as input the research reported in deliverable D1.1 “Concept of Operations” [6], which provides the initial version of the SPR-INTEROP/OSED of the AEON SESAR Solution. The document D1.1 also identifies the initial set of safety, performance and human-machine interaction (HMI) requirements of the AEON solution for the specific use cases defined as relevant in D3.1 “Representative use cases definition”.

During the final validation session, the human in the loop simulation will be organised using the simulation facilities adapted specifically for this simulation and described in D4.1 “Description of the first simulation platform” [11] and subsequent consolidated version D4.2 “Description of the final simulation platform” [12].

The D5.1 also set the basis for the activities that will be reported at the end of the project in the D5.2 “HP Assessment Report”, D5.3 “Safety Assessment Report”, and D5.4 “Cost Assessment”.

This document is also related with the D6.1 “Intermediate dissemination report” where are defined the dates for the evaluation exercises and where are detailed the events which will be used to disseminate the output of the three validation sessions.

Finally, the results of the Solution Assessment process detailed in this deliverable will influence the consolidation of the AEON Concept of Operations, whose final version will be described in D1.2 “Concept of Operations Final version”.

1.3 Intended readership

The intended audience of the solution assessment plan are mainly the AEON Consortium that will use it to plan and manage the validation activities, and the SJU. However, being a public document, the intended readership includes also:

- 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, as it will be publicly available.

1.4 Structure of the document

This deliverable is structured as follows:

- Chapter 1 introduces the purpose of the document, the relationship with other deliverables and its structure.
- Chapter 2 describes the context of the validation activities of AEON, the research question and hypothesis as well as the schedule of validation activities, and the related validation approach and objectives.

- Chapter 3 contains the plan of the Preliminary Evaluation.
- Chapter 4 contains the plan of the Intermediate Evaluation.
- Chapter 5 presents the plan of the Final Evaluation.
- Chapter 6 provides the references.

1.5 List of acronyms

Term	Definition
AEON	Advanced Engine Off Navigation
ATCO	Air Traffic Controller
ATM	Air traffic Management
CBA	Cost-Benefit Analysis
CdG	Charles de Gaulle
CONOPS	Concept of Operations
DBL	Deep Blue
EFB	Electric Flight Bag
ENAC	Ecole Nationale de l'Aviation Civile
E-OCVM	European Operational Concept Validation Methodology
HMI	Human Machine Interface
HP	Human Performance
INTEROP	Interoperability Requirements
NLG	Nose Landing Gear
OSED	Operational Service and Environment Definition
SESAR	Single European Sky ATM Research
SET	Single Engine Taxiing
SJU	SESAR Joint Undertaking
SPR	Safety and Performance Requirements

TFM	Tug Fleet Manager
TUD	Technical University of Delft
VA	Validation Assumption
VO	Validation Objective
WP	Work Package

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 system or single engine taxiing. With this end, the project Consortium is willing to provide a viable solution that integrates the three taxiing technologies into an innovative concept of operations that reduce emissions produced in surface movements, while keeping relatively high airport capacity.

The validation activities are pivotal for the development of the AEON concept of operations (CONOPS) as they allow the Consortium to analyse the fitness of its application in the aviation system.

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 the environment, as well as on human performance, safety, liability, capacity, efficiency, and cost-benefits for the aviation stakeholders involved.

2.1 The AEON concept and tools

In the future the different engine off techniques taken into account by the project (i.e., single-engine, autonomous taxiing solutions and non-autonomous taxiing solutions) may become robust technologies. In this future scenario there will be the need for these different engine-off taxiing techniques to coexist in the airport environment, and be used in a coordinated way, thus overcoming the specific limitations that each of them has in the operations and pursuing the overarching purpose of making ground operations more sustainable and eco-friendlier.

The AEON initial concept of operations and tools aim at supporting the different ground operators involved in the process in sharing their constraints, in order to decide together the best way to allocate the different available taxiing techniques for each flight, and then manage potential operational events that could prevent the initial plan to deliver correctly. In order to achieve this goal, it offers a set of dedicated algorithms, tools, and interfaces.

As represented in the following conceptual image, the AEON solution is planned to influence ground operations at different time phases of the planning, thus affecting the work of different actors.

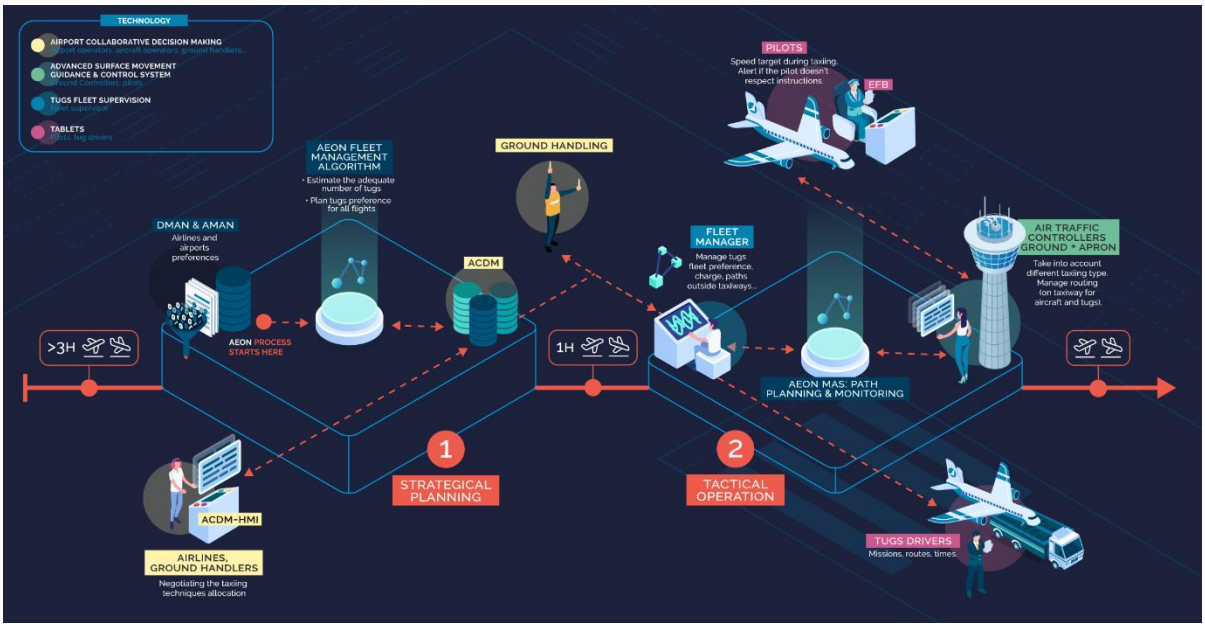


Figure 2. Visual representation of the AEON Initial Concept of Operations

During the **strategical planning phase**, 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. 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 defines the most suitable taxiing technique for each arriving and departing aircraft. More specifically, it defines the airplanes that will be towed by a tug, those that will use electric engine, and finally those that will use single engine taxiing. Not necessary it will allocate all the three techniques in a given period. 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.

The proposed allocation of taxiing techniques to aircraft is then 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 with last minute operational events, requests or needs. One hour before departing/arrival time, the decision is frozen, and the tactical planning phase starts.

During the **tactical planning phase**, a second AEON algorithm, called AEON multi-agent system for tug allocation and path planning, provides HMIs for ATC officers and pilots to manage the actual taxiing. By interfacing with the Advanced Surface Movement Guidance and Control System (A-SMGCS) HMIs, the AEON multi agent system for tug allocation and path planning helps:

- the ground and apron ATCOs to: i) identify the taxiing technique allocated to each aircraft, ii) to define the taxi clearances, especially for towed departing aircraft that will need to stop for detaching process somewhere without disturbing the rest of traffic, and iii) to give real-time updates on remaining taxi time to pilots in order to facilitate engines start-up procedure.

- the fleet manager to reassign tugs when unforeseen operational events imply a change in the initial plan.

In addition, the AEON solution considers that the aircraft using electrical engines for taxiing (or towed by electric tugs) are more easily controlled on speed (i.e., they can take speed target and follow them). Since the common drawback to all engine off taxiing techniques is the lower acceleration level, it would be highly beneficial to avoid stop and go. For this reason, the AEON initial concept of operations considers the possibility of providing speed target to avoid aircraft arriving simultaneously on the same intersection, hence smoothing traffic control. Considering that this new type of ATC clearances could create additional workload and radio frequency usage, the AEON initial concept of operations considers the possibility of giving speed cues to the pilot through datalink, to be displayed on the electronic flight bag.

2.2 Project validation framework

The activities related to the solution assessment plan of the innovative concept proposed by the AEON project is executed within WP5: Solution Performance Assessment. The objective of WP5 is to evaluate the implementation of the proposed concept of operations for autonomous (i.e., e-Taxi), non-autonomous taxiing (i.e., TaxiBots) and Single Engine Taxiing operations in the validation platform developed in WP4 and on the set of use cases identified in the D1.1 and D3.1 [6][7].

The activities that compose the three evaluation phases described in this document, take part from the validation phases described in the E-OCVM [2] and the SESAR HP Assessment process [3]. The activities done in the Preliminary Evaluation aimed at identifying the operational and technical solutions for meeting the target performance identified in the pre-Research & Development (R&D) needs phase (V1). The Intermediate and Final Evaluation will then further refine the AEON operational concept, exploring the individual concept elements, and supporting enablers until the CONOPS can be considered operationally feasible or it can be established that further development is no longer justified (V1-V2).

WP5 (TUD) structures the validation activities into 7 tasks. The **Solution Assessment Plan** (this document) is generated within **Task 5.1 (DBL)** to present the key elements for guiding all the Evaluation Activities of the WP5, supporting a proper evaluation of the AEON concept. The WP5 also includes the following tasks:

- **Task 5.2**, **Scenario implementation in the simulator (ENAC)**, allows to validate the platform setup and the correct conduct of the scenarios.
- **Task 5.3 Human Performance Assessment (DBL)** deals with the human performance and liability assessment of the new concept of operations. This process will lead to D5.2 – HP Assessment Report (T0+22).
- **Task 5.4**, **Safety Assessment (TUD)**, concerns the identification of safety and performance requirements for the AEON CONOPS. This task will lead to D5.3 – Safety Assessment Report (T0+22).

- **Task 5.5, Cost-benefit Analysis for an autonomous aircraft based electric taxi system (TUD)**, develops a Cost-Benefit Analysis (CBA) model for an airline equipping an aircraft with an autonomous e-taxi system.
- **Task 5.6, Cost-Benefit Analysis for non-autonomous electric taxi systems (TUD)**, analyses the cost of the required airport infrastructure to enable non-autonomous electric towing.
- **Task 5.7, Capacity and efficiency assessment (TUD)**, develop a model to estimate the capacity of an airport with the proposed operational concepts of autonomous and non-autonomous aircraft taxiing. This task also includes a preliminary environmental impact assessment.

The results produced by the work made within these last three Tasks, namely T5.5, T5.6 and T5.7, will convey into D5.4 – Cost Assessment (T0+22). Furthermore, a desk analysis will be carried out to identify the potential benefits and cost associated to the deployment of the AEON operational concept.

2.3 Research question and hypothesis

The main **high-level research questions** can be summarized as:

- "How does the AEON concept affect ground movements during the taxi-in and taxi-out phases?"
- "Is the AEON concept acceptable from the safety, human performance, economic, liability and environmental point of view?"

The four main **research hypotheses** to be investigated during the validation activities are:

1. There are no potential showstoppers regarding environmental constraints, and economic aspects can be considered sustainable.
2. The AEON solution does not negatively impact the required safety levels.
3. The introduction of a Tug Fleet Manager role, taxiing allocation algorithms and path planning algorithms enables taxiing actors to benefit the most from engine-off taxiing-capable aircraft and autonomous tugs.
4. The AEON solution tools, and related procedures are acceptable for the involved actors (ATCOs, pilot, …), and ensure proper situational awareness, acceptable workload, liability allocation and an adequate and safe control of the ground movements in taxi-in and taxi-out phases.

These hypotheses are explored at different levels of details in all the evaluation activities.

2.4 Structure and planning of the validation activities

As already anticipated, the AEON Consortium foresees a 3-step validation process to validate the concept of operations developed in the project. In particular, three sets of validation activities, with different objects, aims, levels of analysis and methods used are planned:

- **A preliminary evaluation** made for user needs and initial feedback collection was run with the aviation stakeholders in a set of individual meetings, and in the 1st Advisory Board Workshop held in September 2021. The description of this activity is provided in Chapter 3.
- **An intermediate evaluation** phase will demonstrate selected uses cases of specific features of the solution with various prototypes to a group of Ground ATCos, pilots, airlines, and tug drivers at Roissy Charles de Gaulle (CdG) airport. The demo is expected between March and May 2022 and will allow the Consortium to collect feedback from the end users on specific aspects of the AEON solution. Interest has been expressed also by the Amsterdam-Schiphol airport for hosting a similar validation session, but it is not confirmed yet. The description of this activity is provided in Chapter 4.
- **A final evaluation** will evaluate the final concept as implemented in the validation platform, gathering more detailed feedback, and generating the final project result (Task 1.3), which will be used to consolidate the AEON Concept of Operations, in D1.2 Concept of Operations Final version. The different activities that will contribute to the final validation of the AEON concept, including the human-in-the-loop simulation are described in Chapter 5. This session is awaited by May – June 2022.

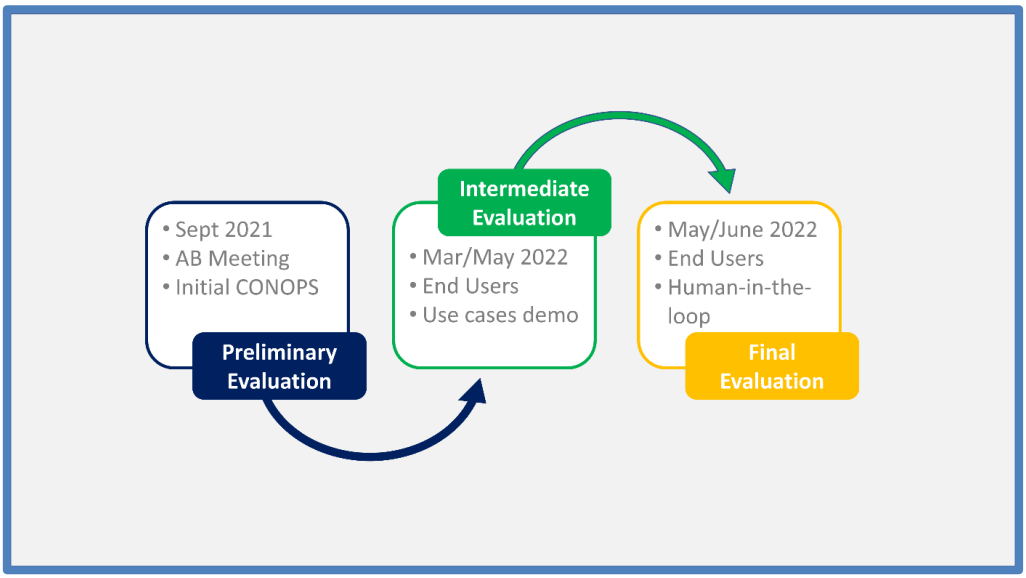


Figure 3. Solution assessment process and approximate due dates

2.5 Validation objectives

A common set of validation objectives has been defined for the project, to be addressed in different ways during the three validation phases described in section 2.3.

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

Table 1. Areas investigated by the project

2.6 Validation limitations and assumptions

The following list of validation assumptions (VA) and limitations have been identified, together with associated mitigations. We consider that the assumption and limitations identified can be considered compatible with the low level of maturity of the AEON Concept of Operations and tool being validated.

Limitations/Assumptions		Mitigations
VA1	The results will be mostly qualitative	At this stage of research project this limitation will not be mitigated.
VA2	No “real” Fleet manager user will be available during the studies, as this is a new role envisaged by the AEON project.	We will ask ATCOs to play this role, since they know the platforms. Possible candidates are also ground handlers. If possible, we will make good use of Amsterdam Schiphol knowledge on the matter.
VA3	The evaluation sessions will use mock-up environment on specific scenario or videos.	The fully integrated solution will be tested in A3.

	The evaluation sessions will assume data available for all stakeholders and ignore algorithms computation time.	
VA4	Empty tugs (TaxiBots) will use the taxiways.	It is a higher constraint than having the possibility to use the service roads.

Table 2. Validation assumptions

3 Preliminary Evaluation | Assessment plan and Results

This section describes the validation objectives, the organisation, and the results of the preliminary evaluation of the AEON operational concept, carried out in September 2021 by the project Consortium with the AEON Advisory Board. Overall, 24 participants attended the meeting: 11 Advisory Board members, 1 representative from the SJU, and 12 Consortium members. The aviation stakeholders that took part in this activity were Eurocontrol, AIRBUS, SAFRAN, DSNA/CDG, The Schiphol Group, Smart Airport System, KLM, To70, Paris Airport and the SESAR JU.

3.1 Organisation and purpose of the preliminary evaluation

The First Advisory Board meeting organised by the AEON Consortium 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 [6]. With this scope, the agenda of the meeting (Table 3) focused on the main areas on which the project concept is built, namely:

- the current functioning of taxiing operations in normal conditions, and possible implications of the greener taxiing solutions being considered by the project: autonomous (i.e., e-Taxi), non-autonomous (i.e., TaxiBots), and Single Engine Taxi (SET).
- the preliminary Cost-Benefit Analysis carried out to assess the constraints and potential benefits associated with the three clusters of techniques studied by the Consortium.
- 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.
- 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 to many insights and was of great help to better understand the needs of the end users and how to design and introduce the new AEON concept of operations.

Time	Activity	Responsible
09:00 – 09:15	Welcome talk and quick summary of the actions taken in the first year of the project	ENAC
09:15 – 09:30	Advisory Board composition and roundtable	DBL
09:30 – 09:45	Overview of new taxing techniques	ENAC/DBL
09:45 – 10:00	Discussion	//
10:00 – 10:45	Presentation of the AEON initial Concept of operations • Cost-benefit Analysis • Multi-agent system for routing • Algorithm for fleet management	ENAC/TUD
10:45 – 11:00	Discussion	//
11:00 – 11:15	Break	//
11:15 – 12:15	Presentation and discussion of the HMI and leads to further explore • A-CDM modifications • TaxiBots supervision tool • Routing suggestion and automated control of vehicles • ATCos and pilots/drivers HMI to support speed cues for smoother traffic	ENAC
12:15 – 12:35	Presentation and discussion of the preliminary safety assessment	TUD
12:35 – 12:50	Final Discussion	//
12:50 – 13:00	Wrap-up and meeting closure	ENAC

Table 3. Agenda of the First Advisory Board meeting

3.2 Validation objectives

The main high-level objective of the preliminary evaluation 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 in sight of the next evaluation phase.

	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 or, alternatively, suggestion 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 impact of the AEON CONOPS on 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 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 4. Preliminary evaluation objectives and success criteria

3.3 Validation methods

The validation methods used during the initial validation with the Advisory Board meeting 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.

3.4 Results

The first part of the Advisory Board meeting focused on the current state of ground operations, allowing the AEON Consortium to better **define the functioning of the non-autonomous taxiing solutions (i.e., TaxiBots) and the times required to start-up the engines for different types of aircrafts.**

The autonomous-taxiing technique (e-Taxi) on the other side, appeared to be easily employable when embedded in the main gear than in the aircraft nose, as per the last case, the technique can produce nose fatigue damages, whereas it doesn't have enough acceleration to efficiently tow all type of aircrafts.

Single Engine Taxiing (SET) operations resulted to be an already mature solution which applicability relies on specific operational and contextual factors, such as manoeuvrability, balance, and runway configurations. These aspects may limit the full deployment of this type of technique in the future.

In the second part of the meeting, the Consortium introduced the AEON initial operational concept, the cost-benefit analysis, the multi-agent system for routing and the algorithm for fleet management. During this session the Advisory Board expressed its concerns about the WheelTugs reliability. **Even when combining WheelTug with SET, the first solution may lead to Nose Landing Gear (NLG) fatigue during the acceleration phase.**

Another comment from the Advisory Board regarded the tactical phase of the AEON CONOPS concerned the Electronic Flight Bag (EFB). The tool did not appear to be a common feature in all aircraft as its availability is currently limited to newer one. Nevertheless, the AEON project expects to handle a very diverse mix of aircrafts. **Aircrafts not equipped with EFB will be monitored by the ground Air Traffic Controller Officers (ATCos) and taken into account in the routing system embedded in the project platform.**

According to the AB members, in the near future airports are likely to opt for a division of roles between Air Traffic Control (ATC) and the APOC (Airport Operations Center), with the main distinction being that live traffic (pushback, taxi, take-off, landing, taxi clearance) will be handled by the ATC, while non-live traffic (towing, empty tugs) will be handled by the airport. **ATC may not be ready to handle a growth of workload caused by increasing tasks complexity. The technologies and regulations, on the other side, appear not to be mature enough to go entirely in the autonomous direction.**

Afterwards, the Consortium presented the Cost-Benefit Analysis on the three techniques presented in the early phase of the meeting. The Advisory Board stressed out AEON not to limit its analysis at exploring the direct correlation between the number of TaxiBots and economic benefits. On the

contrary, the Consortium should try to better understand the beneficial impact of the interaction between some specific runway configurations and the number of vehicles required for standard operations. On this topic, it was also suggested to focus on the solutions that might have a negative effect on the Airport Operations Plan, but which may have an extremely positive impact on fuel and CO2 savings.

In the last part of the meeting, the Consortium presented the Human-Machine Interaction (HMI), the preliminary uses cases and the preliminary safety assessment. **On the HMI, the Advisory Board pointed out that TaxiBots future development will imply new features for dynamic speed limitations**. Then, **the Advisory Board suggested to focus the AEON safety scenarios on hazards strictly related to the employment of greener taxiing techniques, leaving aside those threats that are more related to other solutions.** Finally, the Consortium took back the stage to draw the conclusion and salute the Advisory Board members.

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

The Consortium gathered all the feedback from the Advisory Board to employ them for the refinement of the use cases of the greener taxiing techniques and convey the collected information into the description of the Operational Concept (WP1), prototyping of HMI (WP3), demonstrator integration (WP4) and Solution Performance Assessment (WP5).

4 Intermediate Evaluation | Assessment Plan

This section describes the validation objective and the organisation of the intermediate evaluation of the AEON concepts and tools that will be carried out in the period between March and May 2022.

4.1 Purpose and organisation of the intermediate evaluation

The purpose of the intermediate evaluation session is to explore and assess different alternatives for specific AEON tools (modifications on A-SMGCS, Tugs Fleet Manager HMI and pilots' moving map) with the concerned stakeholders. It is also expected to identify possible showstoppers associated with these tools.

The evaluation will be performed iteratively and will rely on several prototypes, from low fidelity to high fidelity when possible. We will use a setup currently being deployed in Roissy CdG DSNA premises that will allow ATCOs and professionals from ADP to take part in the evaluation sessions. Although representatives from Amsterdam Schiphol have expressed their interest in organising similar evaluation sessions with their personal as well, the feasibility and possible organisation of this evaluation session is still under analysis and discussion.

4.2 Validation objectives

The main objective of this intermediate evaluation is to gather a maximum of feedback from operational staff on specific solutions proposed to address the requirements formulated in D1.1 [6]. This session does not target a validation of the full solution but rather focuses on specific aspects of the solution. It will mostly cover Human Performance area (HP) by assessing the interfaces and interactions that will used by stakeholders (T5.3), but it will also inform the adequation of the path planning algorithms and other KPIs indirectly. Table 5 details the specific objectives of the intermediate validation activities.

For all these objectives, we will assess to which extent the interface and interaction adequately cover the related requirements. The results will inform the design choices made for the interactions that will be specified in D3.2, and the path planning algorithms in D2.1. We will also examine if the results of the assessment suggest modifications of the existing requirements or the creation of new ones.

Validation Objectives	Low level validation objectives	Success Criteria
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).

Human Performance	Tug Fleet Manager (TFM) allocation and supervision. **Explore the design of the TFM HMI to support the supervision and allocation of the TaxiBots.**	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…).
Human Performance	Pilot operation support. **Explore the design of moving map and cockpit tools to support pilot using the AEON tools (TaxiBots, 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.
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). ATOCs are able to indicate that a form of taxiing will not be possible to use.
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 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
	Allocation algorithm performance **Computation time, ability to find solutions**	The allocation algorithm is able to allocate within minutes TaxiBots for all flights during one day of

	acceptable for ATCOs and TFM	operations, indicating the optimal size of the fleet of TaxiBots (strategic phase). At the tactical phase, the algorithm is able to allocate TaxiBots within minutes, by taking into account updates of the arrival/departure times of the flights.

Table 5. Specific objectives of the intermediate validation and related Requirements

4.3 Validation methods

To validate our designs, we will use an iterative approach using a variety of prototypes from low fidelity (wireframes or videos) to working prototypes, when possible, with short scenarios highlighting the particular item to be validated. Since the prototypes will focus on specific aspects of the solutions, we will only involve concerned actors and the actions from other actors will be either described or automatically played by the simulation engine. Participants will be asked to perform specific tasks or scenarios with the prototypes and to fill questionnaires or to participate in follow-up interviews to gather feedback.

4.4 Operational scenario considered

We will create specific scenarios building upon the use cases defined in D3.1 with modified data from a peak traffic recorded at Roissy CdG. We will also create ad-hoc datasets if required. This will also help us ensuring that these use cases will be available for the final evaluation.

4.5 Planning

We will start collecting feedback as soon as the solution is deployed at Roissy CdG and ready to be used by stakeholders. We will create several prototypes and related questionnaires in February to be shared with relevant users from March. For interviews, the planning will be depending on stakeholders' availabilities. If the results suggest major improvements in our designs, we will iterate on the prototypes to perform another evaluation of the updated version.

5 Final Evaluation | Assessment Plan

5.1 Purpose of the Final Evaluation

The Final Evaluation phase will target the consolidated version of the AEON concept of operations and deliver the final conclusions on the validity of the proposed solution.

During the final evaluation phase, the AEON concept (as designed in WP1), algorithms (as designed in WP2) and prototypes (as designed in WP3) will be experimentally tested through simulation (using the simulation platform (designed and implemented in WP4) to evaluate its operational feasibility and collect human performance data.

In addition, a further set of analyses will be carried out to:

a. assess the safety of the concept,
b. perform a cost-benefit analysis of the proposed solution,
c. assess the possible impact on capacity and efficiency,
d. evaluate the environmental impact of the proposed solution and,
e. anticipate liability risks that may be associated to the proposed concept and affect its acceptability.

5.2 Validation activities

To collect the needed information and generate the final results, the final evaluation phase will include different validation activities.

The results of the different activities will be documented in specific assessment reports, which will be then used as input for the consolidation of the AEON concept of operations in the framework of WP1. A critical and comparative review of the results achieved by the different validation activities is not part of the work carried out in WP5. Instead, it will be carried out in WP1 as initial step of the process for the consolidation of the AEON concept of operations. The consolidated version of the AEON Concept of Operations (D1.2) will provide evidence of how the results of the final evaluation phase contributed to the refinement and consolidation of the concept itself.

	Activity	Concluded by	Related deliverable
A1	Human in the loop simulation	Aug 2022	D5.2 HP Assessment Report
A2	Safety assessment	Aug 2022	D5.3 Safety Assessment Report
A3	Cost-benefit analysis	Aug 2022	D5.4 Cost assessment
A4	Capacity assessment	Aug 2022	D5.4 Cost assessment
A5	Efficiency assessment	Aug 2022	D5.4 Cost assessment

A6	Environmental impact assessment	Aug 2022	D5.4 Cost assessment
A7	Liability assessment	Aug 2022	D5.2 HP Assessment Report

Table 6. Final Validation Activities

5.3 Validation objectives

The final evaluation phase will collect information related to all the performance areas investigated within the project, namely Human Performance (HP), Safety, Cost-Benefit, Capacity, Efficiency, Environmental Impact and Liability. In the following table, one high-level validation objective is associated to each of the performance areas, together with criteria and related activities.

	Description	Criteria	Activities
VO1	**Human performance**	The concept enables proper human performance levels, and is considered acceptable by the involved actors	• **A1** Human-in-the-loop simulation
VO2	**Safety**	The concept does not negatively affect safety	• **A1** Human-in-the-loop Simulation • **A2** Preliminary safety assessment
VO3	**Cost-benefit**	The concept enables a sustainable cost-benefit balancing for autonomous / non-autonomous electric taxiing systems	• **A3** Cost benefit assessment
VO4	**Capacity**	The concept enables a suitable exploitation of airport capacity	• **A1** Human-in-the-loop Simulation • **A4** Capacity assessment

VO5	**Efficiency**	The concept enables efficient taxiing operations	• **A1** Human-in-the-loop Simulation • **A5** Efficiency Assessment
VO6	**Environmental impact**	The concept has positive effects on the environmental impact of taxiing operations	• **A1** Human-in-the-loop Simulation • **A6** environmental impact assessment
VO7	**Liability**	The concept does not introduce unacceptable liability risks for actors and stakeholders	• **A7** Liability assessment

Table 7. Validation objectives, success criteria and related activities

According to the E-OCVM [2] validation objectives generation process, the high-level validation objectives above were then decomposed into lower-level, detailed validation objectives to which specific success criteria and validation means were associated. The result of this work is summarised in the following table that contains the detailed validation objectives, validation criteria and validation mean, and data collection methods associated to each validation objective and area.

The SESAR HP [3] assessment process was used as reference and guidance for the definition of the detailed validation objectives and criteria associated to the HP assessment (VO1).

Validation objective	Detailed validation objective	Criteria	Validation mean / data collection methods
VO1 | HUMAN PERFORMANCE			
To validate that the AEON CONOPS does not negatively impact the required HP levels	1.1 The role of the human is consistent with human capabilities and limitations	1.1.1 Roles and responsibilities of human actors are clear and exhaustive	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON
		1.1.2 Operating methods are exhaustive and	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation

		support human performance	
		1.1.3 Human actors can achieve their tasks	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 standard questionnaires on Workload, Trust and Social Acceptance • A1 Quantitative data logs
	1.2 Technical systems support the human actors in performing their tasks	1.2.1 Appropriate allocation of tasks between the human and machine	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 standard questionnaires on Workload and Trust • A1 Quantitative data logs
		1.2.2 The performance of the technical system supports the human in carrying out their task	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 Quantitative data logs
		1.2.3 The design of the human-machine interface supports the human in carrying out their tasks	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 Quantitative data logs
	1.3 Team structures and team communication support the human actors in	1.3.1 Effects on team composition are identified	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 Quantitative data logs

	performing their tasks	1.3.2 The allocation of tasks between human actors supports human performance	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 Quantitative data logs
		1.3.3 The communication between team members supports human performance	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON • A1 standard questionnaire on Social Acceptance • A1 Quantitative data logs
	1.4 Human Performance related transition factors are considered	1.4.1 The proposed solution is acceptable to affected human actors	• A1 Post-exercise group de-briefing • A1 Over-the-shoulder non-intrusive observation • A1 Questionnaire AEON
VO2 | SAFETY			
To investigate the expected benefits that the AEON CONOPS is supposed to provide in terms of safety and identify initial main safety issues	2.1 All actors at all times comply with manufacturer documents and operational safety instructions	2.1.1 All actors at all times comply with safety separation distances	• A2 Quantitative data logs • A1 Over-the-shoulder nonintrusive observation
		2.1.2 Unambiguous communication between all the actors	• A1 Over-the-shoulder nonintrusive observation • A1 Post-exercise group de-briefing • A1 Questionnaire AEON
		2.1.3 Pilots observe their surroundings attentively	• A1 Over-the-shoulder nonintrusive observation • A1 Post-exercise group de-briefing • A1 Questionnaire AEON

		2.1.4 Tug coupling/de-coupling operations and areas are well specified and controlled	• A1 Over-the-shoulder nonintrusive observation • A1 Post-exercise group de-briefing • A1 Questionnaire AEON
	2.2 To identify and investigate previously unknown safety issues	2.2.1 New safety events and hazards are identified and investigated during the validation study	• A2 Quantitative data logs • A1 Over-the-shoulder nonintrusive observation • A1 Post-exercise group de-briefing • A1 Questionnaire AEON
VO3 | COST BENEFIT			
To validate that the AEON solution can be cost effective.	3.1 Cost-benefit modelling, calculation and presentations are clear and representative.	3.1.1 Method of modelling is correct	• A3 Cost benefit methodology
		3.1.2 Calculations are accurate	• A3 Cost benefit calculations
		3.1.3 Presentation of results are comprehensible	• A3 Cost benefit presentation
	3.2 Identify Primary cost drivers.	3.2.1 Primary cost drivers have been identified	• A3 Cost drivers
	3.3 Identify primary benefit drivers.	3.3.1 Primary benefit drivers have been identified	• A3 Benefit drivers
VO4 | CAPACITY			
To validate what the impact of the AEON solution is on airport	4.1 Identify Impacts of the AEON solution on potential airport	4.1.1 All significant capacity	• A4 Capacity bottlenecks

capacity and how negative impact can be mitigated	capacity bottlenecks.	bottlenecks have been identified	
	4.2 Identify possible mitigation measures to limit the impact on airport capacity bottlenecks	4.2.1 Mitigation measures are validated to be effective	• A4 Capacity mitigation
VO5 | EFFICIENCY			
To validate what the impact of the AEON solution is on taxi time and how negative impact can be mitigated	5.1 Identify impacts of the AEON solution on efficiencies not covered in other categories, most notably taxi time	5.1.1 Impact on time has been validated to be representative.	• A5 Efficiency
VO6 | ENVIRONMENTAL IMPACT			
To validate that the environmental impact of the AEON solution is representative	6.1 Identify impact of the AEON solution on emissions and noise	6.1.1 Most significant impact on environmental factor have been quantified.	• A6 Environment
VO7 | LIABILITY			
To validate that the liability risks associated to the AEON solution are acceptable for actors and stakeholders	7.1 The AEON solution is compliant with current regulatory framework	7.1.1 The AEON solution is compliant with current regulatory framework	• A7 Legal Case step 1
	7.2 Liability risks are acceptable for the concerned actors and stakeholders	7.2.1 Liability risks for operators are considered	• A7 Legal Case step 2
		7.2.2 Liability risks for	

		organisations are considered	
		7.2.3 Liability risks for manufacturers are considered	
	7.3 Liability risks mitigations are considered	7.3.1 Means to mitigate the liability risks of the operators are considered (if needed)	• A7 Legal Case step 3
		7.3.2 Means to mitigate the liability risks of the organisation are considered (if needed)	
		7.3.3 Means to mitigate the liability risks of the manufacturers are considered (if needed)	

Table 8. From validation objectives to data collection methods

5.4 A1 | Human-in-the-loop simulation

A human in the loop simulation will be organised with relevant and experienced users, in order to test the AEON concept and tools in a realistic environment and under different operational conditions.

The human in the loop simulation will allow to collect data about how the different actors interact with the system and with each other, as well as their expert feedback on the different aspects to improve or change both in the concept and in the prototype.

The human in the loop simulation will be organised by ENAC, in Toulouse (FR), using the simulation facilities adapted specifically for this simulation and described in D4.1 [11] and D4.2 [12]. All partners of the AEON Consortium will be involved in the organisation, execution, and analysis of the simulation.

Considering the type of project and the level of maturity of the concept, it is anticipated that most of the results will be qualitative rather than quantitative.

5.4.1 Exercise assumptions

As indicated in D3.1 [7], engine-off technologies introduced in AEON are expected to change aircraft's speed profiles on taxiways and to introduce additional vehicles on taxiways. This will have significant impacts on taxi procedures and the way stakeholders operate.

Aircraft will have disparate speed profiles and manoeuvrability levels. This variability will impact airport schedule as it may require more time to reach a given location on the airport using such taxi technologies. Airlines and APTO may have to replan ground handling strategies to cope with longer taxiing time.

Since aircraft will be able to taxi engine-off, pilots will have to plan for engine start time and location to optimise fuel consumption while following engine start-up airline companies' and airports' procedures and avoiding any timeout. In addition, when towed to or from runways, pilots will have to incorporate attaching/detaching time and location with the tug before departure or after landing. Finally, every aircraft will be required to follow speed recommendations to optimise the traffic flow and fuel consumption. Therefore, pilots will have to monitor and control the aircraft speed accordingly.

The assumption of AEON in this exercise is that tugs will use the taxiways. This will increase work demand for routing and communication between ATCOs and taxiways users. Like aircraft, taxi clearances and routes will be needed for tugs drivers to navigate throughout the airport. This could increase ATCOs' workload and intensify verbal communication on ground control frequencies. The heterogeneity of vehicles characteristics on taxiways may create conflicts which will need stakeholders' collaborative efforts to resolve.

On a tactical planning level, the tug fleet manager will be responsible of proposing an allocation plan to provide tugs on time for towing operations to be performed as requested. In particular, the fleet manager will have to assign the towing vehicles to aircraft according to technical requirements and companies' preferences. The FM will also ensure the tugs usage optimisation by dispatching any available tug at any time if required. When incidents arise, available tug may be dispatched to resolve taxiways traffic congestion at the fleet manager's discretion.

5.4.2 Exercise limitations

The AEON Initial Concept of Operation has a very large scope, with implications on several aspects of airport operations, in particular surface management, runway management and overall airport management. It also affects many different actors involved in the management of ground operations.

Although the human in the loop simulation (A1) will focus on the entire concept, not all the aspects of the concept will be simulated. In particular, the ENAC simulation platform and environment will allow to simulate a part of the process, as represented in the following table that shows which requirements will be simulated and which not. A-CDM application and tug drivers' positions will not be simulated in our platform.

The part of the concept of operations and the associated requirements that will not be simulated will be evaluated by means of dedicated feedback collection sessions with the end users, in dedicated sessions of discussion and envisioning arranged during the simulation.

Requirement identifier	Requirement title	Implemented in simulator	Validation activity
REQ-AEON.01-SPRINTEROP-AM01.0001	Tugs allocation module interface	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-CD01.0002	A-CDM application taxi technique choice	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-CD01.0003	A-CDM application interface	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-CD01.0004	AEON without A-CDM	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-RM01.0005	Routing module interface	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-SM01.0006	A- SMGCS application interface	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-SM01.0007	A- SMGCS application interactions	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-SM01.0008	Route environmental impact indicator	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-AC01.0009	Routing for pilots	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-AC01.0010	Communication of AEON recommendations	yes	Human-in-the-loop simulation

REQ-AEON.01-SPRINTEROP-FM01.0011	Tugs fleet monitoring role	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-FM01.0012	Tugs fleet monitoring responsibilities	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-FM01.0013	Tug allocation	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-TU01.0014	Tug driving support	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-TU01.0015	Human-driven tugs commands takeover support	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-TU01.0016	Autonomous tugs commands takeover support	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-FM01.0017	Coordination requests to ATCOs	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-TU01.0018	Coordination requests to tug drivers	no	Feedback collection about the concept
REQ-AEON.01-SPRINTEROP-AC01.0019	Aircraft engine start support	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-TU01.0020	Tugs maintenance support	yes	Human-in-the-loop simulation
REQ-AEON.01-SPRINTEROP-UU01.0021	Ecological decision support	yes	Human-in-the-loop simulation

5.4.3 Validation scenario

The AEON concept of operations requirements will be evaluated through a simulation which integrates a selection of representative use cases from the AEON deliverable D3.1 [7]. In addition, the simulation will be performed with actual traffic data of Roissy – CdG airport from Paris Airport.

To ensure that AEON's new operational concepts are well integrated together, we have selected the relevant use cases with high implementation priority that will provide a frame for evaluating the aspects that will impact the operators' performance with AEON's concepts. These use cases are:

- TO1: Three departures with Engine-off taxiing techniques
- TO2: Tug dispatching
- TO3: Medium traffic with multiple engine-off taxing techniques

These use cases and actual airport data have been combined into a tangible scenario that will drive the evaluation sessions with the final users. This scenario is presented in the next section.

5.4.4 Reference scenario

The reference scenario will play a ground traffic situation from Roissy – CdG airport using ground traffic data from the peak season on the 1st of September 2019. The data show that the ground traffic can reach up to more than 100 aircrafts taxiing on the airport per hour. Therefore, to implement the use case AEON TO3, we have identified one-hour slots with traffic density at approximately 50% of the day with a fair balance between departures and arrivals which we consider as medium traffic.

The data from these slots will be loaded into our improved AEON platform to provide a realistic context to introduce the new AEON concepts to the participants. We will amend the provided data to include at least 3 random departures with electric tugs in line with the use cases TO1 and TO3. The AEON algorithms will provide the route plan and the tug allocation schedule for the scenario, which will last for about 30 minutes.

The main scenario will be then divided into tailored scenarios for each of the participants, the ground controller, the aircraft pilot, and the tug fleet manager, focusing on each role's relevant tasks and AEON operational concepts.

5.4.5 Experimental plan

At this stage, AEON operational concepts integration will be evaluated through a simulation which includes dedicated setup for each role in the CONOPS.

Participants will be performing together the relevant scenarios, which integrates all AEON concept evaluation candidates. Given the exploratory research nature and the maturity level of the project, the concepts integration will be mainly assessed by collecting qualitative data from the participants' performance experience through subjective questionnaires and scientifically proven evaluation methods (NASA TLX, SAGAT, SALSA, SUS…).

Each participant will perform evaluations in a specific setup depending on their role. For instance, pilots will perform the simulation into a cockpit simulator that will provide the relevant AEON concepts implementation such as routing speed profiles on the A-SMGCS interface. Furthermore, ground controllers will perform the simulation into ENAC control tower simulation room which offers a panoramic view on RealTWR's mixed reality airport models. A dedicated setup will be provided for tug fleet management as well. Finally, in order to provide simulation contextual cues, two pseudo pilots positions will also be added to answer the ground controller over the radio and execute the clearances in the simulation.

In addition to the overall concept assessment, we will also collect qualitative feedback to ensure that the AEON individual supporting tools are usable and acceptable as during the intermediate evaluation to consolidate our results.

5.4.6 Subjects of the experiment

According to D4.1 [11] the following working positions will be available in the human in the loop simulation:

- **the ground tower ATC position**

  The ground tower position uses RealTwr (fig.5) for the out of the window view and includes the visualisation of TaxiBots. From this working position the ground controller will be able to manage the traffic and take into account the suggestions produced by the AEON multi agent system for tug allocation and path planning and communicated by the A-SMGCS interface.

- **the pilot position in the cockpit simulator**

  The cockpit simulator is connected to the same simulated world as the ground tower position is integrated in the simulated traffic. A tablet PC will show the routing on a moving map with the rest of the traffic and the speed information.

- **the tug fleet manager position**

  A dedicated position will be used for this new role and its own HMI.

For now, we suppose that the tug drivers would be provided with the same type of HMI as the aircraft pilots and no specific tool need to be developed for them.

The subjects of the experiment are the key operational roles involved in AEON operational concepts namely the ground controllers, the aircraft pilots, and the tug fleet managers. Therefore, in post or recently retired ground controllers and pilots from AEON's partners network will be recruited to perform the simulation.

Since the tug fleet manager has been defined as a new role in the AEON CONOPS, we will recruit pseudo-managers to perform the simulation. As we envisioned the tug fleet manager to have strong knowledge on departures, arrivals and airport traffic procedures, ground controllers will also be recruited to play this role.

Figure 4. Ground tower position with RealTwr view

Figure 5. A320 cockpit simulator

The cockpit can be connected to the ATC ground control position in the same simulation and will allow to test the automatic sending of taxi route / speed profile via datalink and validate the design of the HMI to display it to the pilot. The A320 simulator can be driven on ground to try different engine off techniques.

5.4.7 Validation platform

ACHIL platform will be used as our validation platform. The platform includes several simulators such as ATC tower positions and cockpit simulators. This will allow the investigation of the relevance of AEON operational concepts from the ground controllers' and pilots' perspectives. For AEON, the ACHIL platform will be completed with a fleet manager setup to evaluate the relevancy of this novel key role introduced in AEON CONOPS. An exhaustive description of the ACHIL validation platform is available in the AEON deliverable D4.1 [11].

5.4.8 Validation methods and techniques

To assess the validation objective 1.1 "The role of the human is consistent with human capabilities and limitation", questionnaire such as the NASA Task Load Index will be completed by each participant. In addition, to collect relevant feedback on AEON procedures, the participants will complete the AEON questionnaire as well. These will provide insights into participants' workload and will highlight aspects of AEON that may impact operators' performance.

The validation objective 1.2 "Technical systems support the human actors in performing their tasks" will be assessed by monitoring any deviation from the AEON computed schedules and the scenario completion. Any delay in the flight departures, tug allocations or taxi routes schedules will provide cues of operator performance using AEON interactive systems. Qualitative feedback on the AEON interactive prototype will be collected through the AEON questionnaire as well.

The validation objective 1.3 "Team structures and team communication support the human actors in performing their tasks" will be evaluated through freeze or real-time probes to target situational awareness specifically, using the SALSA questionnaire. Upon completion of the experiment, participants will complete the SART questionnaire to collect subjective data on situation awareness as well.

The validation objective 1.4 "Human Performance related transition factors are considered" will be evaluated through the System Usability Scale questionnaire upon completion of the simulation. In addition, participants answer questions targeted on acceptability of the AEON operational concepts in the final AEON questionnaire.

5.4.9 Identified risks and mitigation actions

The integration of all AEON operational concepts into a single simulation is non-trivial and technically challenging. If the integration is not possible, we will reduce the scope of the demonstration and focus on the evaluation of each of the core tasks proposed in the intermediate evaluation to ensure that we are still able to collect data on AEON concept of operations.

The participants recruitment will be critical to evaluate AEON operational concepts. If access to active controllers cannot be granted, we will recruit control instructors that have experience in ground control position. Moreover, if access to active pilots cannot been granted, ENAC pseudo-pilots may be involved to replace missing pilots. This will ensure that the AEON concepts can be evaluated even though all the participants cannot be recruited or reunited.

5.5 A2 | Safety Assessment

Previously, in the description of the concept of operation in the deliverable 1.1 [6], the most essential safety events and hazards were identified based on existing literature (technical manuals, academic papers, the interview with the advisory board), and classified according to the classical risk matrix. After that, a set of safety requirements was specified to mitigate the risks.

To evaluate the validation criterion 2.1.1 'All actors at all times comply with safety separation distances' the simulated data from the validation experiments will be logged, and then the simulation traces will be checked automatically to establish whether or not the established separation distances were violated during the experiments. In addition, the validation experiments will be monitored visually and non-intrusively to establish cases of loss of separation, which will be further discussed with the participants of the experiments.

The validation criterion 2.1.2 'Unambiguous communication between all the actors' will be observed non-intrusively during the validation experiments. The cases of ambiguous communication will be discussed with the participants after the experiments. Furthermore, an AEON questionnaire to be filled by the participants will be used to establish other cases when communication was ambiguous.

The validation criterion 2.1.3 'Tug drivers and pilots observe their surroundings attentively' first of all will be evaluated by non-intrusively observing the pilots' (and tug drivers', if tug drivers will be enacted by other participants in experiments) behaviour in the simulation, and by post-exercise group de-briefing, to establish which aspects of the simulation environment pilots monitored while taxiing.

The validation criterion 2.1.4 'Tug coupling/de-coupling operations and areas are well specified and controlled' will be evaluated by monitoring the behaviour of the pilots and interaction with other related actors at coupling/uncoupling points. Since the operations at and around these points are new to all actors, they deserve a special attention and will be also discussed at post-exercise group de-briefing, and in the AEON questionnaire.

Since the concept of operation proposed in AEON is new, it is also possible that not previously known hazards and safety-related events will be identified during the validation experiments. These events will be identified by examining simulation data logs, by observing the experiments visually, and by performing post-exercise group de-briefing about safety-related events and from the AEON questionnaire study. The identified safety issues will be further examined by discussing them with members of the advisory board.

5.6 A3 | Cost-Benefit Analysis

For the cost benefit assessment will be validated in three separate components.

The validation criterion 3.1.1 will be assessed by experts in the airport field and checks if the most important factors have been taken into account in the correct way. Especially investment vs. operational costs with respect to current cost accounting and costs and benefits shared by different actors need to be identified.

Validation criterion 3.1.2 goes into more details on the actual calculations and uses experts to check if variation in the assumed cost and benefit values have the expected result on the outcome. The actual values are not part of this validation, as too much uncertainty is present, especially with items as fuel costs, electricity costs and the purchase costs of towing vehicles.

Validation criteria 3.1.3 uses airport experts to check if the outcomes of the cost benefit analysis are presented in such a way that they help airport decision makers to make an informed decision on if and how to implement the AEON solution at their airport.

Validation criteria 3.2 and 3.3 check with experts if the most important cost and benefit drivers in the model have actually been identified what is needed to quantify these.

5.7 A4 | Capacity assessment

It is expected that the AEON solution can have an impact on airport capacity, most notably including a reduction of runway capacity due to taxiway congestion leading to additional time between movements above the minimum separation times. This can be causes by lower taxi speeds, but especially the time needed to connect and disconnect towing vehicles near the runway.

Validation criteria 4.1 uses expert from ATC and airlines to identify if all possible impacts on capacity have been identified and if they can be taken into account in a human-in-the-loop simulation.

Validation criteria 4.2 users expects to check the possible changes can be made to the airport infrastructure or operations to limit theses effects and if they can be taken into account in a human in the loop simulation.

5.8 A5 | Efficiency assessment

The AEON solutions are likely to lead to an increase in taxi and other ground handling time, especially when connecting and disconnecting tugs form the aircraft. Validation criteria 5 checks if all impacts on taxi time have been identified and how these can be quantified, using experts on respective areas, by comparing normal, single-engine, autonomous and towed taxi times.

5.9 A6 | Environmental impact assessment

The AEON solution primarily aims to reduce fossil fuel consumption on the ground. Secondary, also gaseous emissions and noise will mostly be reduced; however, these are generally not regulated at this level. Validation criteria 6 uses experts to check if the qualitative impact of these reductions in fuel on the airport operation can be achieved. Generally, these reductions will be calculated by taking the fuel consumption and multiplying it with the ICAO emissions indices for each aircraft type.

5.10 A7 | Liability assessment

The Legal Case method and tool [13] [14] [15] will be applied to conduct the liability assessment.

The Legal Case is proprietary method and a tool developed and owned by Deep Blue, to proactively identify and mitigate liability risks in complex and safety-critical organizations, in particular the Air Traffic Management (ATM). Designed with the purpose of supporting the analysis and plan of liability implications of new operational concepts and tools during their design process, it moves from the considerations that liability is one of the inherent properties of the ATM system, in the same way as safety, security, human performance and environmental sustainability.

The basic approach behind the method is that every system component shall be designed in a coordinated and integrated way, in order to ensure that the final product is not only safe and secure, but also effective from the human performance perspective, environmentally sustainable and, not less important, acceptable from the liability point of view.

The method consists of a structured 4-step process whose main purpose is to help the analyst in determining, tracing and managing the liability risks of the different stakeholders involved, and of a number of dedicated supporting tools. It helps identifying how liabilities are attributed and distributed among the stakeholders, what are the liability risks of each stakeholder, how the liability allocation might affect the stakeholders' acceptability of the tool, and possible mitigations to reduce the legal risk. The structure by case makes the process straightforward and creates synergies and possible points of contact with both the Safety Case and Human Performance Case.

The following diagram represents the process of the Legal Case.

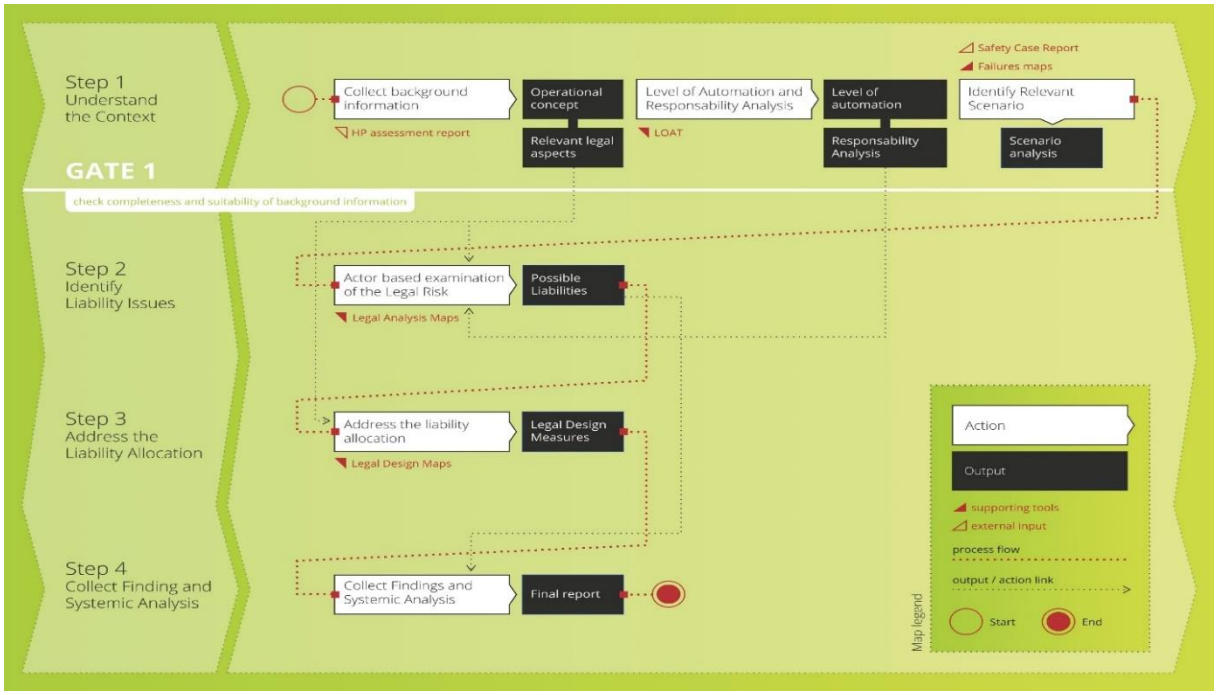


Figure 6. The Legal Case Process

The first step "**understanding the context**" focuses on the collection and elaboration of background information about the subject of the study (in our specific case, the AEON Concept of Operations). It moves from understanding the technical, operational, and regulatory context of operation and the associated operational concept. This is essential to analyse the level of automation of the tool (i.e. how the human-machine cooperation develops) as well as to understand the role of the different actors involved and their task and associated responsibilities in the different situations. The third and last activity of step 1 foresees the identification of possible failure scenarios that could be relevant in terms of liability implications. So, at the end of step 1, as represented by the black boxes in the diagram, it provides: (i) the analysis of the operational concept and of relevant legal aspects, (ii) the classification of the level of automation and the analysis of the actors' task responsibilities, and (iii) the identification of relevant scenarios.

The second step "**identify liability issues**" has the aim of performing an actor-based examination of the legal risks. This activity is supported by specific Legal Analysis Maps like the one represented in Fig.2, that help identifying which liabilities could be associated to each category of actors involved and under which conditions they can be considered liable.

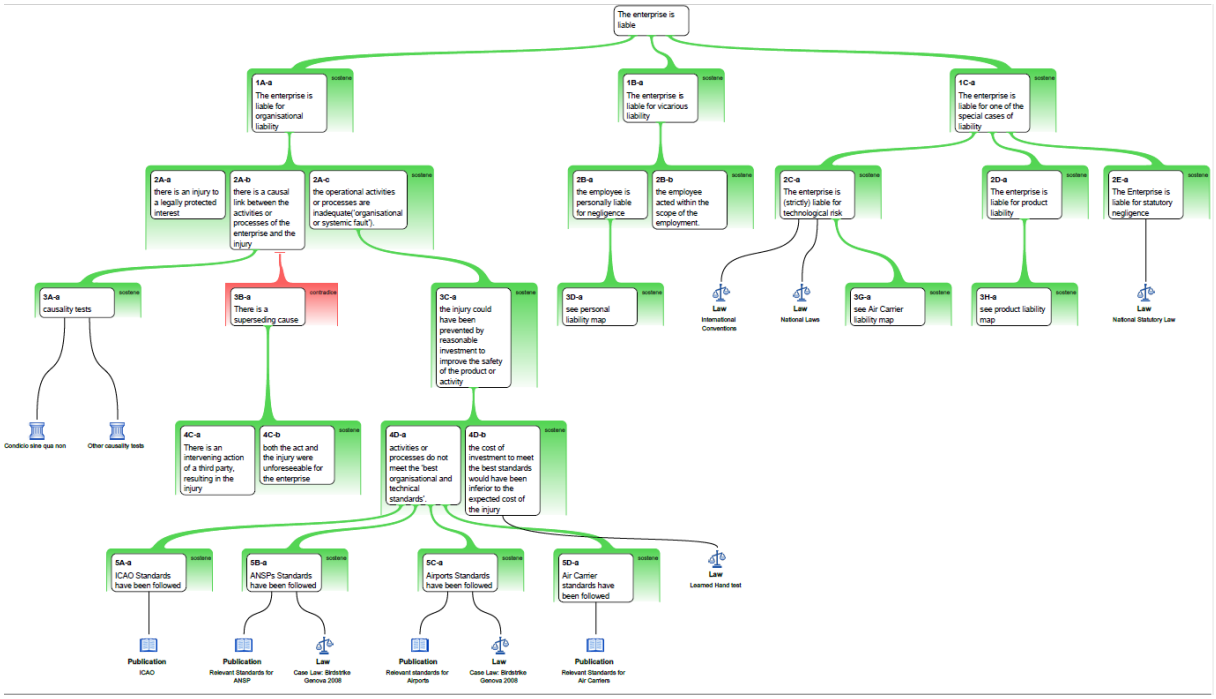


Figure 7. Example of argumentative legal maps used in the Legal Case process

The third step "address the liability allocation" has the aim of identifying legal design measures and mitigations that can reduce the risk for the actors involved. It is worth noticing that mitigations can be of different nature: they could imply a redesign of the operational concept and/or the tool, foresee contractual clauses to protect the actors and/or require insurance coverage. The three strategies are not mutually exclusive, and their adoption depends on the specific situation, including the design stage of the operational concept. It is in fact evident that changing the operational concept could be relatively affordable at the early stages of the design but becomes progressively more difficult as soon as the level of maturity of the concept and of the tool increases.

The four step "collect findings and systemic analysis" has the aims of documenting the process, keeping tracks and justifying the reasons behind specific decisions that may have been made during the process. Should the Legal Case be applied to study liability implications of a new operational concept, the final report of the Legal Case could reveal particularly of help in case of future improvements that may affect the concept.

The application of the Legal Case during the validation of the AEON operational concept, will focus on the identification of the liability risks of all the actors involved use of the Legal Case and their possible mitigations. A particular attention will be paid on aspects of liability attribution and risks that can be associated to roles, procedures and working methods involved in engine-off taxiing operations, in particular of towed aircraft. A novel aspect of the AEON operational concept foresees the possibility that different actors could be responsible of the movement of aircraft during taxiing operations, depending on the purpose of the action. In particular, it is foreseen that the autonomous tug driver could be fully in charge of the taxiing operations until the tug is de-coupled from the aircraft. One of the purposes of the Legal Case application would be to check the suitability and acceptability of this responsibility allocation in terms of liability risks for all the concerned actors (while in parallel, the same proposal will be validated also in terms of human performance and safety).

5.11 Integration of results

The results of the different activities will be documented in specific assessment reports, which will be then used as input for the consolidation of the AEON concept of operations in the framework of WP1. A critical and comparative review of the results achieved by the different validation activities is not part of the work carried out in WP5. Instead, it will be carried out in WP1 as initial step of the process for the consolidation of the AEON concept of operations. The consolidated version of the AEON Concept of Operations (D1.2) will provide evidence of how the results of the final evaluation phase contributed to the refinement and consolidation of the concept itself.

6 References

[1] SESAR 2020 Requirements and Validation Guidelines Wave 2 (Edition: 00.02.01)

[2] EUROCONTROL (2010). E-OCVM Version 3.0: European Operational Concept Validation Methodology. Brussels, Belgium: EUROCONTROL.

[3] SESAR Human Performance Assessment Process V1 to V3 - including VLD

[4] AEON First Advisory Board meeting (September 2021)

[5] Burian B. K., and others, Designing Realistic, Full-Mission, Human-in-the-Loop Aviation Simulation Studies: Lessons Learned, Proceedings of the Human Factors and Ergonomic Society 55th Annual Meeting. 2011.

[6] AEON D1.1 – Concept of Operations Initial version

[7] AEON D3.1 - Representative use cases

[8] SESAR, Safety Reference Material, Edition 4.0, April 2016
https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=1795089.13&resetHistory=true&statInfo=Ogp&domainName=saas

[9] SESAR, Guidance to Apply the Safety Reference Material, Edition 3.0, April 2016
https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=1795102.13&resetHistory=true&statInfo=Ogp&domainName=saas

[10] Visser, H.G., Wijnen, R.A.A., Chin, R.T.H., Walker, W.E., Lang, N.A., Keur, J., Kohse, U., Veldhuis, J., De Haan, A.R.C. The Airport Business Suite: A Decision Support System for Airport Strategic Exploration, Proceedings of the 3rd AIAA Aviation Technology, Integration and Operations Forum, Denver, Colorado, USA, 17-19 November 2003.

[11] AEON D4.1 – Description of the first simulation platform

[12] AEON D4.2 – Description of the final simulation platform

[13] Sartor G., Contissa G., Schebesta H., Laukyte M., Lanzi, P., Marti, P., Tomasello, P. (2013). The Legal Case, Proceedings of ATACCS 2013, May 2013, pp. 96–110.

[14] Lanzi, P. (2020), Automation and liability in ATC, ATC Magazine Revista professional de control de tránsito aéreo, N.103 April 2020, pag.30-39.

[15] Lanzi, P., Hermosilla D. (2020), Automation in ATM. Are you liable? ATC Magazine Revista professional de control de tránsito aéreo, N.104 June 2020, pag.52-61.