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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

AEON aims at fostering the use of environmentally friendly ground operations techniques such as autonomous (i.e., e-taxi), non-autonomous (i.e., TaxiBots) or Single Engine Taxiing (SET). For the developed AEON concept of operation, preliminary safety assessment was performed. The assessment was largely qualitative and aimed at identifying and exploring important safety issues and related safety scenarios that could be investigated by more in-depth quantitative safety risk assessment approaches. Initially, safety events, safety hazards, safety objectives, safety requirements and safety scenarios were identified for the AEON concept based on existing literature. These initial safety findings were discussed with AEON's Advisory board, which resulted in identification of several other important safety issues. Subsequently, safety was considered in the context of selected use cases that were demonstrated to the stakeholders involved in airport surface movement operations. These demonstrations resulted in the identification of additional safety events and hazards, which were discussed with the stakeholders. In the final validation study, some of the prominent safety issues identified before were further studied in the context of a human-in-the-loop real-time simulation study and by a questionnaire administered to the participants after that the simulation study. The results obtained in all these phases of safety analysis are described in this deliverable. In the end, a set of recommendations is provided with the points for further, more in-depth, quantitative safety assessment.

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1 Introduction

1.1 Purpose of the document

This document provides preliminary safety assessment results for the solution and concept of operation developed in AEON. Note that the safety assessment was done mostly qualitatively, in an explorative manner to identify as many as possible safety issues and to understand their precursors and consequences by discussing them with stakeholders involved in airport surface movement operations. This goal and the level of safety analysis are in line with the exploratory nature of AEON project and its low TRL level. In the future, based on the findings presented in this report, a more in-depth quantitative safety assessment study needs to be performed.

1.2 Intended readership

The intended audience of this report are mainly the AEON Consortium that will use it to consolidate the AEON CONOPS, 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.

1.3 Related documents

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

1. D1.1 Initial Concept of Operations, providing the concept that has been assessed in the validation activities.
2. D3.1 Use Cases, detailing the use cases defined to design the AEON concept and system and partially used also during the validation activities.
3. D4.1 and D4.2 presenting the description of the platform used for the real-time simulation arranged as the final validation session.
4. D5.1 Validation Plan, that describes the overall validation approach of the project and details the specific validation plan formulated for the safety assessment.
5. D5.2 Human Performance Assessment report, which describes the results of 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.

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1.4 Structure of the document

The document is structured in 5 sections:

- Section 1 is the present introduction
- Section 2 introduces the context of the preliminary safety assessment. In particular, it provides an overview of the AEON solution and of the related concept of operation, as well as describes the overall validation approach of which safety assessment is a part.
- Section 3 describes the safety assessment results obtained in different phases of the validation approach.
- Section 4 contains conclusions and recommendations.
- Section 5 contains references.

1.5 Glossary of terms

Term	Definition	Source of the definition
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	AEON D1.1
Tug 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.	AEON D1.1
Single Engine Taxi	Taxi solution that involves the use of only half the number of engines installed to generate the energy needed for taxiing	AEON D1.1
Tug	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.	AEON D1.1

Table 1: Glossary of terms

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1.6 Acronyms

Term	Definition
AEON	Advanced Engine Off Navigation
AMS	Amsterdam Schiphol Airport (IATA code)
ANSP	Air Navigation Service Provider
A-SMGCS	Airport Surface Management Ground Control System
ATCO	Air Traffic Controller
ATM	Air Traffic Management
CDG	Paris Charles De Gaulle Airport (IATA Code)
CONOPS	Concept of Operations
DSNA	Direction des Services de la Navigation Aérienne
EASA	European Union Aviation Safety Agency
EHAM	Amsterdam Schiphol Airport (ICAO code)
E-OCVM	European Operational Concept Validation Methodology
HMI	Human Machine Interface
HP	Human Performance
LFPG	Paris Charles De Gaulle Airport (ICAO Code)
OSED	Operational Service and Environment Definition
RTS	Real-Time Simulation
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research Programme
SET	Single Engine Taxi
TD	TaxiBot Driver
TFM	Tug Fleet Manager
TRL	Technology Readiness Level
VA	Validation Assumption

WP	Work Package

Table 2: Acronyms and terminology

2 Preliminary safety assessment: approach and context

Preliminary safety assessment was performed for the novel concept of operation for environmentally friendly airport surface movement operations developed in AEON. In this section we shall first briefly summarize the developed concept. A more detailed description of the concept is provided in deliverable D1.1 [1].

Safety assessment was done as a part of the overall AEON solution validation plan [2]. An overview of the safety assessment approach is provided in Section 2.2.

2.1 An overview of the concept of operation

The concept of operation is based on three taxiing techniques: single-engine taxiing, autonomous taxiing, and tug-enabled taxiing. Single-engine taxiing involves only half the number of engines installed to generate the energy needed for taxiing. Tug-enabled taxiing is based on the use of hybrid towing vehicles, such as TaxiBots, which, unlike the normal pushback trucks, can tow full aircrafts to near the start of the runway, without the aircraft having to start its engines. Autonomous taxiing relies on electric motors, like E-Taxi system or WheelTug, that are embedded in landing gear or nose wheel gear to allow aircraft to pushback and taxi without their jet engines running.

By means of a set of dedicated tools and interfaces for the different ground operators, as well as dedicated algorithms, the AEON solution supports operators to decide on the best use of the different available taxiing techniques for each flight and then manage potential operational events that would prevent the initial plan to be executed correctly.

The AEON solution supports the operators at different planning phases. During long-term planning, a support tool will help estimate the adequate number of tugs for specific traffic conditions. Then, the best allocations of taxiing technique to each arriving and departing aircraft will be determined considering the arrival and departure sequences and the operational constraints of the tugs fleet. For the tactical phase, AEON provides interfaces for ATC officers and pilots to manage the actual taxiing. Advanced Surface Movement Guidance and Control System (A-SMGCS) HMIs will:

- identify the taxiing techniques of each aircraft;
- help define the taxi clearances, especially for towed departing aircraft that will need to stop for detaching process somewhere without disturbing the rest of traffic;
- give real-time updates on remaining taxi time to give to the pilot in order to facilitate engines start-up procedure, and
- help reassign tugs when operational events modify the initial plan.
- The following figure provides a representation of the AEON eco-system from long-term planning to short-term planning of operations.

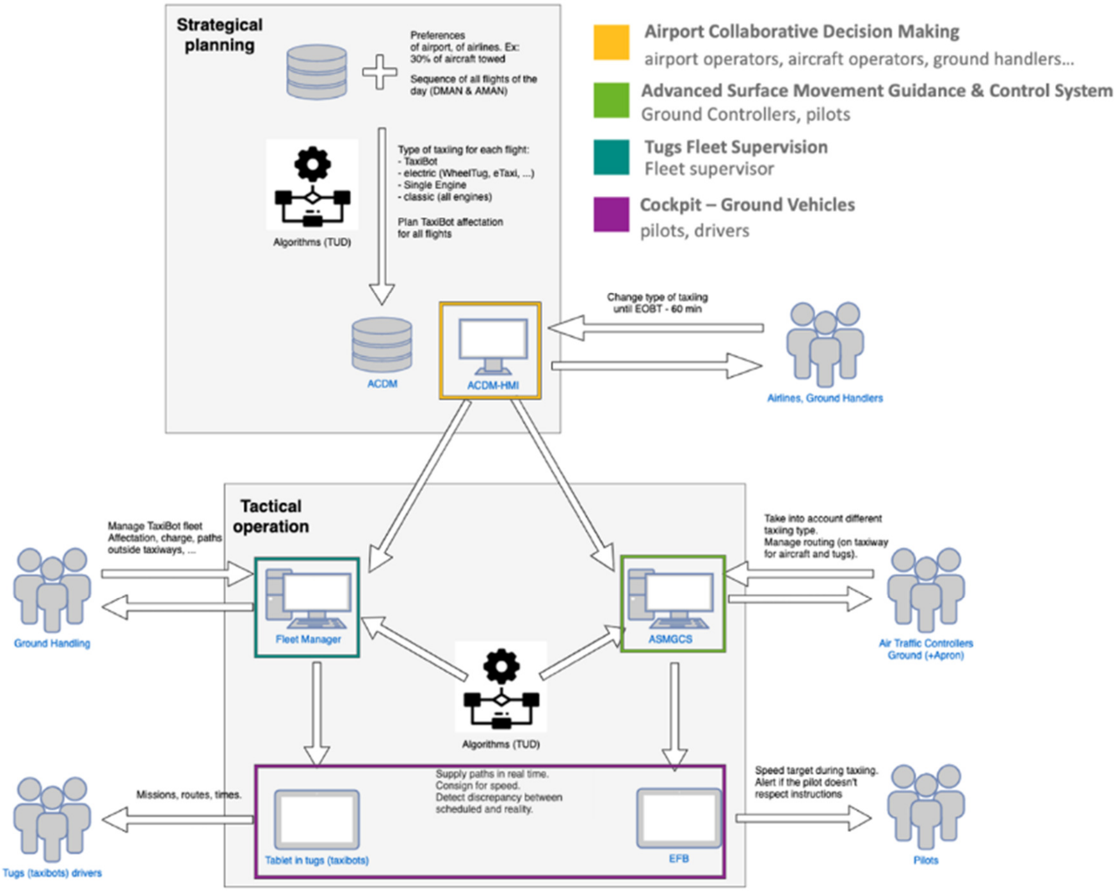

Figure 1: Overview of AEON eco-system from long-term planning to short-term planning of operations

2.2 An overview of the preliminary safety assessment approach

Usually, a well-defined concept of operation is required to perform safety assessment. Since the development of the novel AEON concept of operation started from scratch and took place during a large part of the AEON project, safety assessment activities were performed throughout the project, in three phases described in the validation plan (deliverable D5.1 [2]). In such a way, the concept of operation was validated progressively during its development. Note that only a preliminary, qualitative safety assessment with limited input from experts was feasible to perform within the frames of the project. On a higher methodological level, the safety assessment activities were aligned with the SESAR Safety reference material [6] and Guidance to Apply the SESAR Safety Reference Material [5], as discussed in the following.

As stated in deliverable D5.1 [2], the safety criteria for the AEON solution were defined as the AEON concept should not negatively affect safety of airport surface movement operations.

In the following we will describe safety assessment activities that took place in the three validation phases.

In the preliminary evaluation phase, after the initial version of the AEON concept of operation was developed, it was provided to the AEON's advisory board for reviewing (September 2021). Note that the technical models underlying the concept of operation and the simulation environment were still in development at this point. The concept of operation was not yet elaborated for specific airports, such as AMS or CDG. As stated in deliverable D1.1, section 3.2, the operational environment considered all kinds of ground operations in the airport environments, from high to low complexity. However, more emphasis was put on airports being characterised by high complexity ground operations. Three operational scenarios were described at a high level in deliverable D1.1, section 3.3.2.6 to illustrate the concept of operation: 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 purpose of the preliminary safety evaluation session, which was carried out in September 2021, during the 1st Advisory board meeting of the project, was to identify important safety hazards related to the provided concept of operation that would form the basis for safety objectives and safety requirements using 'failure approach' [5]. These hazards were identified based on the analysis of the corresponding operational services, described in particular by ATM operational requirements in Deliverable 1.1, section 4.1. Because of the limited availability of experts, only most prominent safety hazards were considered, which arise from new ways of operating in the AEON concept of operation (in particular, use of tugs). Safety of single engine mode of taxiing has been extensively studied before, and is already taken into account in flight manuals. Therefore, it was not considered in AEON. Expert knowledge on autonomous taxiing was limited, therefore we were able to identify only a few safety hazards. Most of the safety assessment was related to tug-enabled taxiing, also because several members of the advisory board had knowledge and experiences with this mode of taxiing. They also independently performed safety analysis of such operations within their organizations, identified hazards and determined risk levels associated with them using the standard risk assessment matrix. Their expert opinion was taken into account in determining the risk levels of the hazards identified in own study. In addition, using this information, we determined the severity classes of some hazards directly related to the Taxiway accident model and the RWY accident model, described in [5]. Since only qualitative safety assessment was performed in AEON, no quantitative safety objectives were calculated for the identified hazards. Instead, the identified qualitative safety objectives for the hazards were directly reflected in the safety requirements listed in Deliverable 1.1, section 4.2.

The intermediate evaluation phase 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 Schiphol (AMS – EHAM). 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 SESAR ALBATROSS project. No ATCO took part in the session at Schiphol.

The operational environment represented detailed maps of CDG (for the session at CDG) and of AMS (for the session at AMS) in a computer simulation environment, and the following operational use cases from Deliverable 3.1, section 3 were considered:

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

Note that as stated in deliverable D5.1, the intermediate evaluation phase did not target a validation of the full AEON solution, but mostly covered Human Performance area by assessing the interfaces and interactions used by stakeholders. In particular, different alternatives for functionalities and interfaces for specific AEON tools (namely, Tugs Fleet Manager HMI, multiagent system for routing and pilots' moving map) were considered. These sessions were also used to collect more relevant safety

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hazards in the context of the considered simulated scenarios. Again, the 'failure approach' was used based on the list of ATM requirements from Deliverable 1.1.

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.

The final evaluation session was carried out in July 2022 at ENAC using human-in-the-loop real-time simulation (RTS) in which ground air traffic controllers (ATCOs) from DSNA could manage realistic traffic samples using the concept of operation and the prototypes developed by the AEON project. The RTS lasted 3 working days and involved 7 ATCOs.

The operational environment used in the final evaluation session focused exclusively on Paris Charles De Gaulle (CDG) airport, using ground traffic data from the peak season on the 1st of September 2019. Pseudo pilots and pseudo tug drivers were simulated. The operational use cases, which were considered in the intermediate evaluation session (TO1, TO2 and TO3), were also used in the final evaluation session. These use cases are representative for nominal operations based on the AEON concept of operation. In addition to these use cases, use case TO6 "Dispatching tug to a departure delayed aircraft", described in Deliverable 3.1, which considers a disturbed condition (a delayed aircraft) was used in the evaluation. Other non-nominal situations were not considered in this study because of time constraints and additional implementation and experimental complexity.

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

Limitations/Assumptions		Mitigations
VA1	The results are mostly qualitative and based on experts' feedback	At this stage of research project this limitation was considered acceptable and thus was not mitigated.
VA2	No "real" Tug Fleet Manager user was available during the studies, as this is a new role envisaged by the AEON project.	ATCOs were requested to play this role, and used the validation session to study if this solution is feasible/acceptable and to explore the existence of other possible candidates.
VA3	The evaluation sessions used mock-up environment on specific scenario or videos.	At this stage of research project this limitation was considered acceptable and thus was not mitigated.
VA4	Empty tugs (TaxiBots) used the taxiways.	It is a stronger constraint than having the possibility to use the service roads. The validation sessions were used to explore the acceptability of this solutions, and how to implement the alternatives.

Table 3: Validation assumptions

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The occurrence of the identified safety hazards during the simulation was observed ‘over-the-shoulder’, as well as detected in datalogs. Furthermore, safety-related aspects were evaluated by a post-run questionnaire and a post-run de-briefing, which will be discussed in Section 3.

3 Safety Assessment Results

In this section the safety-related findings from the preliminary, intermediate, and final evaluation sessions are provided.

3.1 Safety-related findings from the preliminary evaluation session

In the preliminary evaluation session, using the 'failure approach' a set of relevant safety hazards was identified for the AEON solution. This list of hazards was based on existing literature and the expert opinion of the Advisory Board members. Furthermore, the expert opinion was used to classify these hazards using the risk assessment matrix with the risk severity and risk probability defined as shown in Table 4. Some of these hazards, which could be related to the existing Accident Incident Models of SESAR, were also classified using the SESAR severity classification schemes. In particular, the runway collision model and taxiway accident model from [5] were used. The complete list of safety hazards and of the related safety requirements is provided in deliverable D1.1.

Probability of occurrence				Probability of occurrence	
1	Virtually impossible	1x every 5 years	Never heard of it	A	No injury or no damage to assets
2	Improbable	1x per year	Has happened here	B	Accident with slight injuries (downtime < 3 days) or slight damage to assets
3	Rare	1x per month	I have already seen it	C	Accident with slight permanent health damage (downtime > 3 days) or minor damage to assets
4	Occasionally	1 x per week	I see this more often	D	Accident with severe permanent damage to health or major damage to asset(s)
5	Often	Multiple times per day	I see this often	E	Accident resulting in death or massive damage to assets

Table 4: Definition of the risk probability and risk severity used in the expert assessment for the identified safety hazards

Here we list only the most critical ones, which were also recognized as important by the Advisory Board members.

For tug-enabled taxiing:

H1: Excessive nose landing gear fatigue.

Risk category assessed by experts: 3C

H2: Bumping of a tug into wings, antennas, driver cabin, gear doors, gear struts.

Risk category assessed by experts: 2D

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SESAR severity category: TWY-SC1. Rationale: collision situation, when a tug has come in physical contact with an aircraft

H3: Jet engine blast during engine start-up on other aircraft taxiing behind.

Risk category assessed by experts: 2C

H4: Weather-related slipperiness of a tug.

Risk category assessed by experts: 3C

SESAR severity category: TWY-SC3. Rationale: a tug driver can prevent a near taxiway collision.

H5: Stress caused by time pressure, high workload and external traffic such as intense traffic.

Risk category assessed by experts: 2C

For autonomous taxiing:

H6: Low pilot's visibility of the surrounding area during pushback.

Risk category assessed by experts: not assessed

H7: Clutch failure.

Risk category assessed by experts: not assessed

For single-engine taxiing:

H8: Loss of braking capability and nose wheel steering while taxiing on uphill slopes or slippery surfaces.

Risk category assessed by experts: 2B

SESAR severity category: TWY-SC3. Rationale: pilot can prevent a collision with another aircraft

H9: Jet blast, especially of wide-body aircraft.

Risk category assessed by experts: not assessed

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In addition, several other safety hazards were discussed, which in particular were identified during the safety risk assessment for the sustainable taxi pilot with a tug at Amsterdam Airport Schiphol in 2020.

One of the prominent hazards is related to the confusion of priorities of aircraft and different types of ground vehicles operating at Schiphol in different traffic situations. Note that this hazard is relevant not only to the tug-enabled taxiing, but also to the mix of the taxiing techniques considered in the AEON solution.

Formal regulations, in particular issued by EASA, such as SERA 3210, describe right-of-way for different actors involved in the airport ground operations. In particular, the following is stated in SERA 3210:

(iv) Subject to the provisions in (iii), 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, taxiing or being towed;

(B) vehicles shall give way to other vehicles towing aircraft.

Pilots, air traffic controllers or other actors involved in ground operations may consider a taxiing aircraft-tug combination to be a lower priority towed aircraft. This would lead to false expectations about the level of priority and behaviour of this actor and may lead to reduced safety margins. For example, a pilot observing a taxiing aircraft-tug combination may wrongly assume to have the right of way. Another example: during the control transfer between air traffic controllers, an air traffic controller would forget about the special status of a taxiing aircraft-tug combination and would wrongly apply the priority rules.

For the mixed mode of operation:

H10: Pilots and ATCos may confuse the priorities stemming from the right-of-way regulations for different actors involved in the airport ground operations, which may result in incorrect expectations about the behaviour of these actors.

Risk category assessed by experts: 3B

SESAR severity category: TWY-SC4 or TWY-SC3. Rationale: either ATCo or pilot can prevent a collision with another aircraft by reacting to the loss of separation.

Furthermore, during the discussion with the Advisory Board experts, **tug coupling/de-coupling locations were identified as safety-critical**. This is largely because the tug drivers are supposed to couple/de-couple tugs manually, walking on operationally active airport surface on which aircraft with running engines operate. This is particularly relevant for the mixed mode of operation, when aircraft taxi with running engine(s).

H11: Tug drivers may be affected by aircraft with running engines around the tug coupling/de-coupling locations.

Risk category assessed by experts: 3D

H12: Pilots may miss coupling/de-coupling points, which may disturb the ground traffic.

Risk category assessed by experts: 2A

One more relevant hazard considered by the Advisory Board stems from the fact that a tug connected in front of an aircraft is not visible from the aircraft's cockpit. This lack of visibility could result in unintended runway incursion, when the aircraft would stop too late at the runway holding point and the tug would appear at the protected area of the runway.

H13: Unintended runway incursion by a tug, when pilot, because of the lack of visibility, would stop the aircraft too late at the runway holding point and the tug would appear at the protected area of the runway.

Risk category assessed by experts: not assessed

SESAR severity category: RWY-SC5. Rationale: runway monitoring could prevent a runway incursion

Another relevant hazard which was discussed during the Advisory Board Meeting was communication problems with a tug. When communication with the tug is lost, an extra radio frequency is provided to re-establish contact with the tug. However, this may lead to distraction of the pilot.

H14: Pilot distraction because of the use of an extra radio frequency when communication with the tug is lost.

Risk category assessed by experts: 3B

3.2 Safety-related findings from the intermediate evaluation session

During the intermediate evaluation session, when the selected use cases were demonstrated using the prototypes developed in the project to the stakeholders involved in airport surface movement operations, the discussion about other relevant safety risks continued.

In this evaluation phase four more safety hazards were identified in discussion with the experts.

Before the start of the pushback/taxi operation, data about the aircraft being connected to the tug should be entered to the tug's computer (mass, center of gravity). Based on this data, the tug would determine the aircraft type (a tug supposed to be used for aircraft for which it is certified). If this data is not correct, this may lead to damage. In the validation scenario, only narrow body aircraft could have used tug vehicle, which makes safety hazard H14 particularly relevant.

H15: Wrong data provided to the tug's computer.

Risk category assessed by experts: 2B.

Checks in the cockpit to be performed after engine start will be postponed from before taxiing to after (or in some cases during) taxiing at the start up point. Due to the lower taxi speed of the tug-enabled

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taxiing than the regular speed, the pilots may experience time pressure, which may lead to configuration errors (flaps/stabilizer trim and airco panel) resulting in a rejected take-off.

H16: Rejected take-off as a result of delayed checks and lower taxi speed.

Risk category assessed by experts: 2C.

The maximum speed of a tug depends on the taxiway conditions (i.e. presence of water, snow, ice) and the airport regulations. If these conditions are unknown or over-estimated, the aircraft-tug combination may taxi with a too high speed. This could lead to loss of control when braking or in a turn, resulting in aircraft damage and/or a taxiway excursion.

H17: Too high speed of the aircraft-tug combination for the taxiway conditions.

Risk category assessed by experts: 1D.

A pilot may forget about a connected tug and switch off the hydraulics or the tug driver would install the bypass pin used to bypass hydraulic system steering on aircraft, which would make steering of aircraft nose gear impossible, and during pushback may result in aircraft damage. The experts evaluated this risk as low.

H18: A pilot may forget about a connected tug and switch off the hydraulics or the tug driver would install the bypass pin, resulting in no steering of nose gear during pushback.

Risk category assessed by experts: 1D.

Furthermore, the experts indicated that **miscommunication issues** are possible between different actors involved in the airport surface movement operations executed using the AEON concept. In particular, such problems may occur between air traffic controllers and tug fleet managers. Ground traffic control becomes a demanding task under high traffic conditions, when interaction between air traffic controllers and tug fleet managers intensifies. This increases the probability of miscommunication. Furthermore, active communication with tug fleet managers could substantially increase the workload of air traffic controllers, which could have a negative effect on the interaction between them and pilots (miscommunication issues). The final evaluation session tested an electronic communication between ATCO and TFM, however it proved to be unnecessary. It was suggested that only tug drivers would need to communicate with ATCos directly. However, it was also discussed that ATCos and TFM could be located in the tower next to each other to be able to directly communicate and discuss particular cases, when necessary.

Miscommunication/lack of coordination is also possible between a tug driver and a pilot during the handover of control over the tug movement, directly after pushback, as well as in the process of uncoupling.

H19: Miscommunication issues between the actors involved in the AEON solution

Risk category assessed by experts: not assessed.

3.3 Safety-related findings from the final evaluation session

Based on the safety-related findings from the preliminary and intermediate evaluation sessions, validation objectives with the related criteria and data gathering methods were identified in deliverable D5.1 (a relevant part of the table from D5.1 is provided below).

Note that many of the identified hazards (e.g., H1, H4, H7, H8, H11, H12, H17) would require a high level of modelling of physical details, which was not feasible within the limited time frames of the project. In the final evaluation, we focused on the use cases and scenarios which are representative for the nominal operations of the AEON concept of operation. Next to safety, they were also used to evaluate the HP aspects in the context of the same human-in-the-loop real-time simulation (RTS) study. Non-nominal situations were not considered in this study because of time constraints and additional implementation and experimental complexity.

The RTS study in particular focused on safety-critical tug coupling/uncoupling operations (criterion 2.1.4 in the table below related to hazard H12). The behaviour of all actors involved in these operations was observed during the human-in-the-loop real-time simulation trials, as well as analysed by the AEON questionnaire and post-exercise group de-briefing.

Also, special attention was given to the quality of communication between all involved actors (criterion 2.1.2 related to hazards H19, H5 and H10), in particular air traffic controllers, as communication largely effects situation awareness. Lack of situation awareness is repeatedly reported as one of the most essential safety hazards often leading to safety incidents/accidents. During the human-in-the-loop real-time simulation trials, it was observed how air traffic controllers prioritized traffic.

Taxiing with a tug attached to an aircraft requires attentive observation of pilots of their surroundings (criterion 2.1.3 related to hazards H2, H6, H13, H5). As was indicated by experts, pilots may confuse the priorities of taxiing vehicles. In particular, they may assume an aircraft-tug combination to be a towed aircraft and unjustifiably presume to have the right of way, which may lead to reduced safety margins. Since a tug attached to an aircraft is not visible from the cockpit, a pilot should be attentive not to collide with any object and not to trespass.

In addition to the objectives considered above, the usual objective of maintaining separation between all aircraft and ground vehicles was considered in the validation study (criterion 2.1.1, in particular related to hazard H2). Furthermore, the objective of identifying previously unknown safety issues during the validation study was considered (criterion 2.2.1).

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Validation objective	Detailed validation objective	Criteria	Validation means / data collection methods
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

Table 5: Safety-related objectives, criteria, and data collection means from D5.1

In the following the findings related to each validation criterion are described.

3.3.1 Findings related to maintaining separation (criterion 2.1.1)

The criterion 'All actors at all times comply with safety separation distances' was first evaluated by observing human-in-the-loop real-time simulation trials. At the beginning of the first simulation trial, it occurred multiple times that separation between aircraft, between aircraft and tugs, and between tugs was lost. However, the maintenance of separation has been improving throughout the simulation trial. In the second half of the first simulation trial and in the subsequent trials no separation was lost. The problems with separation at the beginning of the first trial could be attributed to the familiarization phase, in which the participants learned the tools and the concept of operations.

As can be seen from the assessment of the air traffic controllers of the statement 'During the exercises the safety was at an appropriate level' from the general AEON questionnaire (Fig.2), most of the air traffic controllers perceived safety to be very high (on the scale 0-5) during the validation trials. Maintaining separation is an important safety goal in the airport surface movement operations, which apparently was perceived by participants as achieved at a high level. Only one participant (ATC #6) gave a low score on this aspect. However, this participant provided consistently the same low score on all other safety aspects.

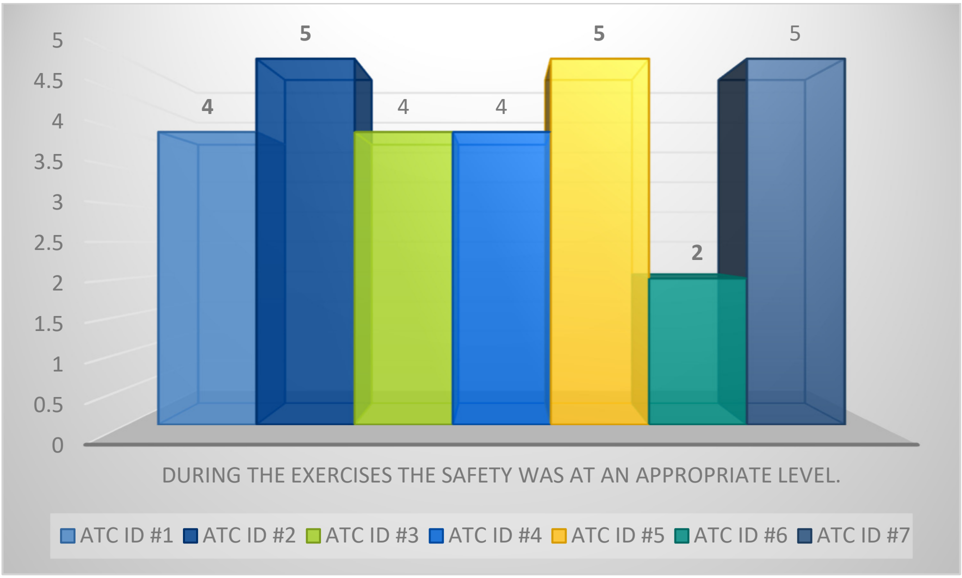

Figure 2: General Questionnaire: during the exercises the safety was at an appropriate level.

3.3.2 Findings related to communication (criterion 2.1.2)

The assessment of the criterion 'Unambiguous communication between all the actors' in Fig.3 indicated communication issues. However, 4 of 7 controllers still valued this criterion highly. More detailed elaboration on this point is provided in deliverable D5.2 on human factors assessment. Here we discuss only the key observations related to the criterion.

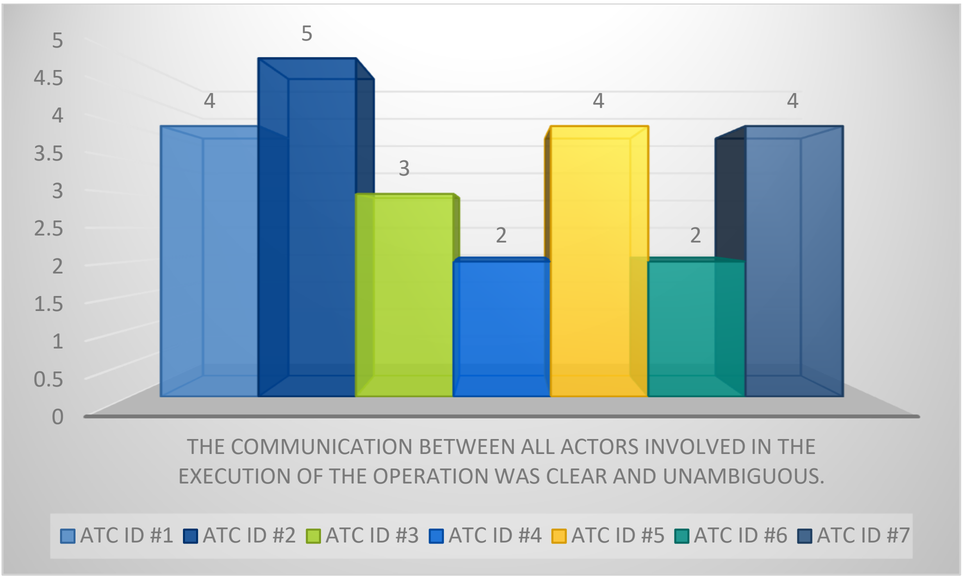

Figure 3: General Questionnaire: The communication between all actors involved in the execution of the operation was clear and unambiguous.

The interaction between the air traffic controllers and the tug fleet manager was often problematic. The air traffic controllers were not able to process all information provided by the tug fleet manager in time, partially because they were busy with other tasks, and sometimes ignored their messages. However, even in these cases it was still possible for air traffic controllers to control traffic safely, because the tug drivers had direct communication with air traffic controllers and contacted them for instructions.

3.3.3 Findings related to observation (criterion 2.1.3)

The assessment of the criterion ‘Pilots observe their surroundings attentively’ in computer simulation has many differences from the assessment of such a criterion in real (physical) operations. However, with the degree of realism provided by AEON’s validation platform, all the involved human actors were able to perform their tasks, largely as they are accustomed to in real life. Furthermore, they managed to properly execute different types of taxiing techniques considered in the AEON solution and in the validation use cases. As was mentioned in section 3.3.1, at the beginning of the validation study there were issues with separation by air traffic controllers (loss of separation was noticed too late), but those could be attributed to the initial familiarization phase, since they did not happen after the air traffic controllers became familiar with the concept of operation.

No issues of prioritization of traffic (in particular of aircraft-tug configurations) were observed during the validation study. The study participants largely complied with the rules described in the AEON concept of operation, which is also reflected in their assessment of the statement ‘I always performed these operations as described in the concept of operation’ in figure below. Deviations from the rules (e.g., aircraft started moving without obtaining the corresponding instruction from the air traffic controller) sometimes happened because of a high workload of pseudo-pilots, who managed several aircraft.

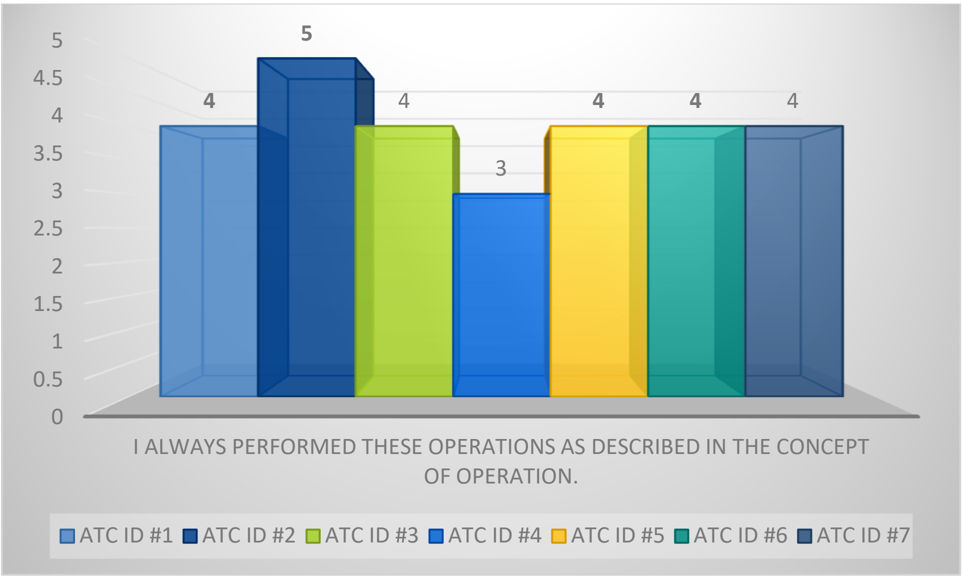

Figure 4: General Questionnaire: I always performed these operations as described in the concept of operation.

3.3.4 Findings related to coupling/uncoupling operations (criterion 2.1.4)

Concerning the evaluation of the criterion 'Tug coupling/de-coupling operations and areas are well specified and controlled' the opinions of the controllers were divided: 4 controllers evaluated it very highly, whereas 3 controllers had concerns (see figure below).

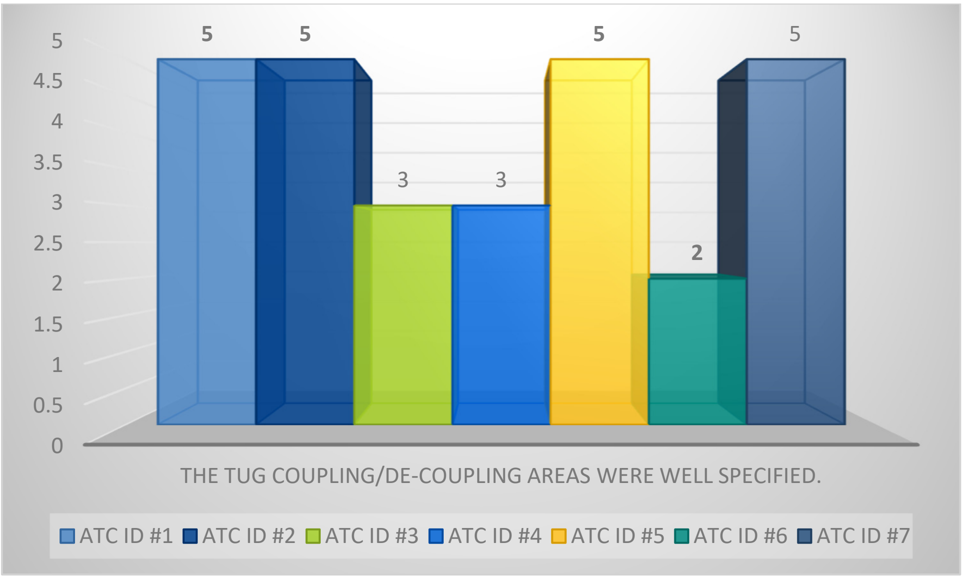

Figure 5: General Questionnaire: The tug coupling/de-coupling areas were well specified.

Although the air traffic controllers were always able to lead the airport-tug configurations to such points, often queues formed there, which required intensive interaction between pseudo-pilots and air traffic controllers.

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3.3.5 Findings related to new safety hazards (criterion 2.1.4)

During the post-exercise group de-briefing the participants did not identify any additional safety issues, which were not considered in AEON before. In general, their perception was that safety was at the acceptable level during the validation exercise.

Also, over-the-shoulder observations and data logs did not provide any new safety issues except those that were considered before.

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4 Conclusions and recommendations

4.1 Conclusions

In the process of preliminary safety assessment, many relevant safety issues and safety hazards H1-H19 were identified which stem from tasks of different stakeholders involved in the AEON concept and interaction between them.

The preliminary qualitative risk assessment was done based on expert opinion of the involved stakeholders and existing literature. Some of the identified important safety hazards were further studied in the context of a human-in-the-loop real-time simulation study. Despite the realism-related limitations of such a study, some important safety hazards, in particular related to communication between ATCOs and TFM, workload of ATCOs interacting with many pilots and tug drivers, and coupling/de-coupling operations became evident, and would require more detailed safety analysis studies.

4.2 Recommendations

Based on the preliminary safety analysis, it is advised to update the concept of operation with the following safety requirements:

R1. Pilots and tug drivers shall comply with the maximum speed of the aircraft-tug combination, which depends on the taxiway conditions and the airport regulations (related to hazard H17)

R2. Pilots shall ensure that the hydraulics is switched on when a tug is connected to the aircraft to make steering of aircraft nose gear possible (related to hazard H18)

R3. Before pushback and taxi operations tug driver shall ensure that the data entered to the their tug's computer about the connected aircraft is correct (related to hazard H15)

R4. All stakeholders involved in the airport surface movement operations shall comply with clearly defined right-of-way rules (related to hazard H10)

R5. Pilots shall pay special attention to the location of tugs attached to their aircraft in order not to collide with any object and not to trespass any protected area (related to hazard H13)

The final evaluation session tested an electronic communication between ATCO and TFM, however it proved to be unnecessary. It was suggested that only tug drivers would need to communicate with ATCos directly. It was also discussed that ATCos and TFM could be located in the tower next to each other to be able to directly communicate and discuss particular cases, when necessary. However, these suggestions require further analysis and can't serve as the reliable basis for the update of the concept of operation concerning the ATCo and TFM roles now.

From the preliminary safety analysis, it was evident that operations at tug coupling/de-coupling locations need to be studied in more detail, as they could present risks to both people (tug drivers) and equipment. These risks need to be quantified. Also the location of such points on the airport surface should be considered from the safety point of view.

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Furthermore, the consequences of high workload of an air traffic controller that would control and interact with multiple aircraft and tugs need to be examined from the safety perspective.

In AEON's final validation study, different prioritisation schemata used by ATCOs to control traffic did not lead to visible safety issues. However, in real world it may still be the case. Therefore, it is advised to study the safety effects of misinterpretation of the right-of-way rules.

One of the important discussions among the project participants and the advisory board members concerning the concept of operation was related to the use of airport service roads by tugs. If tugs would use only taxiways, even when they are not attached to aircraft, it would create additional traffic complexity and workload for ATCos, which could be substantial under high traffic conditions. This situation could be (partly) mitigated by allowing tugs to use airport service roads to return to the gate area. However, not every service road is suitable to be used by any tug, and also not every load/unload point can be easily connected to a service road, because of limitations of the airport infrastructure. In the future, it is recommended to explore how taxiways and service roads could be used, possibly in combination, to ensure acceptable safety levels.

Because of the physical/spatial nature of many safety hazards identified by experts, it was not possible to study them by a human-in-the-loop real-time simulation. Nevertheless, such hazards also need to be studied in the future, either by real life experiments or by high-fidelity models based on real data and expert knowledge.

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5 References

[1] AEON D1.1 – Concept of Operations Initial version, 2021

[2] AEON D5.1 – Solution Assessment Plan, 2022

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

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

[5] Guidance to Apply the SESAR Safety Reference Material, Edition 00.03.00, 2016

[6] SESAR Safety Reference Material, Eurocontrol, Edition 00.04.01, 2018

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