SAFELAND Initial Concept

Deliverable ID:	D1.2
Dissemination Level:	CO
Project Acronym:	SAFELAND
Grant:	890599
Call:	H2020-SESAR-2019-2
Topic:	SESAR-ER4-30-2019
Consortium Coordinator:	Deep Blue
Edition date:	15.01.2021
Edition:	00.01.00
Template Edition:	00.02.00

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Joonas Lieb/DLR	Project Manager	02.11.2020
Max Friedrich/ DLR	Human Factors	02.11.2020
Ana Martins/ DLR	Human Factors	02.11.2020

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Stefano Bonelli/DBL	Project Coordinator	
Pasquale Junior Capasso/EUSC	Certification/ Regulation Expert	
Supathida Boonsong/LFV	ATC Specialist	
Laurence Rognin/ECTL	Project Manager	
Aymeric Trzmiel/ECTL	Validation Expert	
Pascal Marx/ECTL	ATC Specialist	
Andreas Triska/SWISS	Project Manager	
Ricardo Reis/EMB	Project Manager	

Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Stefano Bonelli	Project Coordinator	15.01.2021

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

Document History

Edition	Date	Status	Author	Justification
0.01	02.11.2020	ToC	Joonas Lieb	ToC
0.02	05.11.2020	Initial draft	Joonas Lieb, Max Friedrich, Ana Martins	Initial draft of the deliverable
0.03	08.12.2020	Draft	Joonas Lieb	Draft sent to partners for review

0.04	14.12.2020	First internal review	Stefano Bonelli, Pasquale Junior Capasso, Supathida Boonsong, Laurence Rognin, Pascal Marx	First internal peer review
0.05	06.01.2021	Final draft	Joonas Lieb, Max Friedrich, Ana Martins	Final draft sent to partners for review
0.06	13.01.2021	Final internal review	Stefano Bonelli, Pasquale Junior Capasso, Supathida Boonsong, Laurence Rognin, Aymeric Trzmiel	Final internal peer review
1.0	15.01.2021	Final release	Joonas Lieb	Final version ready for submission

Copyright Statement

SAFELAND

SAFE LANDING THROUGH ENHANCED GROUND SUPPORT

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 890599 under European Union's Horizon 2020 research and innovation programme.

Abstract

This deliverable *D1.2 SAFELAND Initial Concept* describes the initial version of the SAFELAND concept, with different implementation options in case of pilot incapacitation in Single Pilot Operations (SPO). An online workshop was held on the 27th and 28th October 2020, where the three variants of a SAFELAND concept were elaborated, focusing on re-assigning the functions, tasks and responsibilities between the involved entities (i.e. ATC, AOCC, GS and automation) after the pilot incapacitation has occurred. Each variant of the concept has a different focus as to who is mainly responsible for controlling or issuing commands to the aircraft (GS, automation or ATC). The variants were described by three key elements, namely the Function allocation diagram, the Interaction diagram and the Location of the Ground Station. These elements are the same as used in Task 1.1 to describe the model of flight tasks. This is the level of detail that is considered most suitable at this initial level of concepts generation: it permits to have a clear high-level view of the main concepts elements and to start investigating advantages, disadvantages as well as constraints and to formulate open questions.

The key attributes of the developed variants of a SAFELAND concept can be identified as follows: First, in each variant of the concept the Ground Station shall be located at AOCC in order to ensure a fast and efficient communication line between the GSO and other airliner employees as well as to ensure that the liability for the aircraft remains at the airline. Second, due to liability concerns each variant concluded that flight authority cannot be transferred to automation but would have to be given to a human operator on ground. Third, Group ATC introduced a new actor into the ATM framework (apart from a GSO) named "dedicated ATCO" in order to support the GSO in controlling the aircraft from the ATC side.

Table of Contents

List of Tables

List of Figures

List of acronyms

Term	Definition
A/C	Aircraft
AI	Artificial Intelligence
AOCC	Airline Operation Control Center
AP	Autopilot
ATC	Air Traffic Control
ATCO	Air Traffic Controller
C2 datalink	Command & Control datalink
CPDLC	Controller Pilot Data Link Communications
CS	Certification Specification
CMS	Crew Monitoring System
DAA	Detect And Avoid
DH	Decision Height
FMC	Flight Management Computer
FMS	Flight Management System
GS	Ground Station
GSO	Ground Station Operator (Remote Ground Pilot)
HF	Human Factors
ILS	Instrument Landing System
KPI	Key Performance Indicator
METAR	Meteorological Aerodrome Report

NAS	National Airspace System
NIL	No Item Listed
OESD	Operational Event Sequence Diagram
PIC	Pilot In Command
RPAS	Remotely Piloted Aircraft System
RTCA	Radio Technical Commission for Aeronautics
SA	Situation Awareness
SJU	SESAR Joint Undertaking
SMS	Safety Management System
SOCA-CAT	Social Organisation and Cooperation Analysis - Contextual Activity Template
SPO	Single Pilot Operations
TAF	Terminal Aerodrome Forecast
TCAS	Traffic Alert and Collision Avoidance System
TMA	Terminal Manoeuvring Area
UAS	Unmanned Aircraft System
WP	Work package

Table 1: List of Acronyms

1 Introduction

1.1 Purpose and scope of this document

In the first deliverable of WP1 (D1.1 Model of Flight Tasks) the functions that need to be executed to enable safe flight operations of a CS-25 certified aircraft in controlled airspace were described. Methods from Cognitive Work Analysis (i.e. work domain analysis, control task analysis, and social organization and cooperation analysis) were used to derive the functions and allocate them to the different actors. In a next step the interactions between those actors for selected, critical functions and flight phases were described. The analysis was carried out for dual, single and remotely piloted aircraft and the differences between the different aircraft configurations were discussed.

The scope of deliverable *D1.2 SAFELAND Initial Concept* is to describe the initial version of the SAFELAND concept, with different implementation options in case of pilot incapacitation in Single Pilot Operations (SPO). More details are provided in chapter 2.

1.2 Structure of the document

This document consists of 7 chapters entailing several subsections each. The chapters and their contents are the following:

- Chapter 1 describes the purpose and the scope of this deliverable. In addition, chapter 1 describes the structure of the document.
- Chapter 2 provides the framework of the conducted workshop and presents the methodologies used during the workshop. Moreover, this chapter describes the objectives and the organisation of the workshop, as well as details about the scope of the workshop. In addition, chapter 2 describes the expected outcomes of the conducted workshop.
- Chapter 3 entails the outcomes and findings developed by Group Automation focussing on automation for the initial SAFELAND concept. This chapter describes the function allocation and interaction diagrams developed by the group. Moreover, different options for the location of the Ground Station (GS) are discussed.
- Chapter 4 describes the outcomes and findings developed by the Group GS for the initial SAFELAND concept. Similar to chapter 4, this chapter entails the re-assignment of functions towards a Ground Station Operator (GSO), an interaction diagram between the remaining entities, as well as discusses different options for the location of the GS (e.g. AOCC vs. outsourced facility).
- Chapter 5 presents the outcomes and results developed by Group ATC during the workshop. This chapter entails a re-organisation of the function allocation with focus on the Air Traffic Controller, the interaction diagram for the remaining entities, and a discussion on the most sensible location for a GS.

- Chapter 6 concludes the workshop findings detailing key similarities and differences between the proposed variants of the concept and provides aspects that might need further work in the future, including major challenges of the variants.
- Chapter 7 lists the references used within this document.

2 Methodology

As mentioned in chapter 1.1, the scope of deliverable *D1.2 SAFELAND Initial Concept* is to describe the initial version of the SAFELAND concept, with different implementation options in case of pilot incapacitation in Single Pilot Operations (SPO). Previous studies and research projects considered two main approaches to deal with pilot incapacitation: Replacement Through Automation and Second Pilot Displacement to the ground (Neis et al., 2018; Bilimoria et al., 2014).

The former requires a high level of automation onboard which would handle the aircraft from the moment incapacitation is detected to selecting the most suitable airport and guiding the aircraft to it, without any (or almost any) human intervention from the ground, apart from monitoring duties (ACROSS, 2016a; Neis et al., 2018; Stimpson et al., 2016).

The latter requires advanced automation with ground support offered by a remote pilot. This approach has been investigated more in-depth and it has been the focus of most of the research studies on SPO. In this instance, the remote pilot replaces the single pilot in case of incapacitation, with the support of automation and of ATC (Bilimoria et al., 2014; Lachter et al., 2014; Yixiang et al., 2017).

In order to develop and elaborate the SAFELAND concept of operations an online workshop was held on the 27th and 28th October 2020 considering both approaches. However, as stated in the project proposal (SAFELAND, 2019), the focus of SAFELAND is on the ATM aspects, therefore it was decided to include a third mixed approach with focus on the ATCO and elements taken from the other two. The main goal was to assess if and how some of the remote piloting functions could reasonably be transferred to an ATCO, what assumptions would need to be made and how feasible this option could be.

Therefore, in this document we present three variants of a SAFELAND concept, focusing on re-assigning the functions, tasks and responsibilities between the involved entities (i.e. ATC, AOCC, GS and automation) after the pilot incapacitation has occurred. Each concept variant has a different focus as to who is mainly responsible for controlling or issuing commands to the aircraft (automation, GS or ATC).

For the purpose of this document the initial SAFELAND concept will be described by three key elements, namely:

1. Function allocation diagram (Step 1) based on SOCA-CAT (for details please refer to chapter 2.2 and SAFELAND, 2020): The function allocation diagram was used to re-assign required functions in a flight operation onto the remaining actors after the pilot incapacitation has occurred. Chapter 2.2 describes this methodology in detail.

2. Interaction diagram (Step 2) based on OESD (for details please refer to chapter 2.3 and SAFELAND, 2020): An OESD can be used to illustrate and describe the interactions between operators and artefacts within a system (Harris, Stanton & Starr, 2015). In the SAFELAND concept the operators are the remaining actors (e.g. ATC) after the pilot incapacitation has been detected, the artefacts are the different means of interaction (e.g. via radio communication, data exchange, etc.), and the system is the aircraft in the emergency situation.

3. Location of the Ground Station (GS) (Step 3): As the location of a ground station for (at least) monitoring the aircraft in SPO is deemed to have a significant implication on the SAFELAND concept, different options for the location of the GS were weighed, to finally conclude on the most reasonable one.

These three elements are the same as used in Task 1.1 to describe the model of flight tasks and permit a high-level view on the main aspects of each implementation option. These elements will be used to present the different variants of the SAFELAND concept to external experts and getting feedback (Task 3.2).

In the end, the main objective in SAFELAND is to derive and evaluate various concepts for (1) transferring aircraft control and (2) controlling the aircraft from the ground or by onboard automation after a pilot incapacitation has occurred.

2.1 Approach

In this deliverable (D1.2 *Initial Concept*), different variants of the initial SAFELAND concept were derived and evaluated with regard to their feasibility. For deriving the initial concepts, the following activities were carried out:

- A **workshop** with experts from different fields within the project consortium was organized. The aim of the workshop was to start drafting and analysing three alternative approaches to handling single pilot incapacitation. Three independent groups worked on the different concepts.
- After the workshop, each group **refined** their concepts and described the concept in more detail and answered the open questions left from the workshop.
- As a last step, all involved partners carried out a final **integration** and review of the concept.

Each concept will be presented to the advisory board within the scope of a one-day online workshop scheduled for January 2021. Based on the comments and suggestions of the advisory board members, one concept will be retained, further developed and described in D1.4 *Final Concept*.

The next two section describe the methods used to develop the function allocation and operational event sequence diagrams (OESD). More information on these diagrams is provided in deliverable D1.1.

2.2 Function allocation diagram

A social organization and cooperation analysis (SOCA-CAT) is a method to visualize the function allocation in a socio-technical work system, such as an aircraft. In a SOCA-CAT, the functions are mapped against the different situations that a work system experiences. For each function and situation, it is coded, if (1) the function is active in the respective situation and (2) who is involved in the execution of the function. At this stage there is no consideration of which of the actors is best placed to conduct the activities necessary to execute the function, nor is there consideration of the best way of completing the activities.

The functions identified during the analyses of D1.1 were mapped against the situations that an aircraft will encounter between the single pilot incapacitation and the landing roll. The situations the functions were mapped against are (1) pilot incapacitation, (2) top of descent, (2) descent, (3) initial and intermediate approach, (4) final approach and landing and (5) landing roll. The actors upon which the function could be allocated were (1) the GSO, (2) the automation, (3) ATC and (4) the Airline Operations and Control center (AOCC). Figure 1 depicts the empty function allocation template provided to the attendees of the workshop. **Error! Reference source not found.** shows the functions used for developing the function allocation diagram.

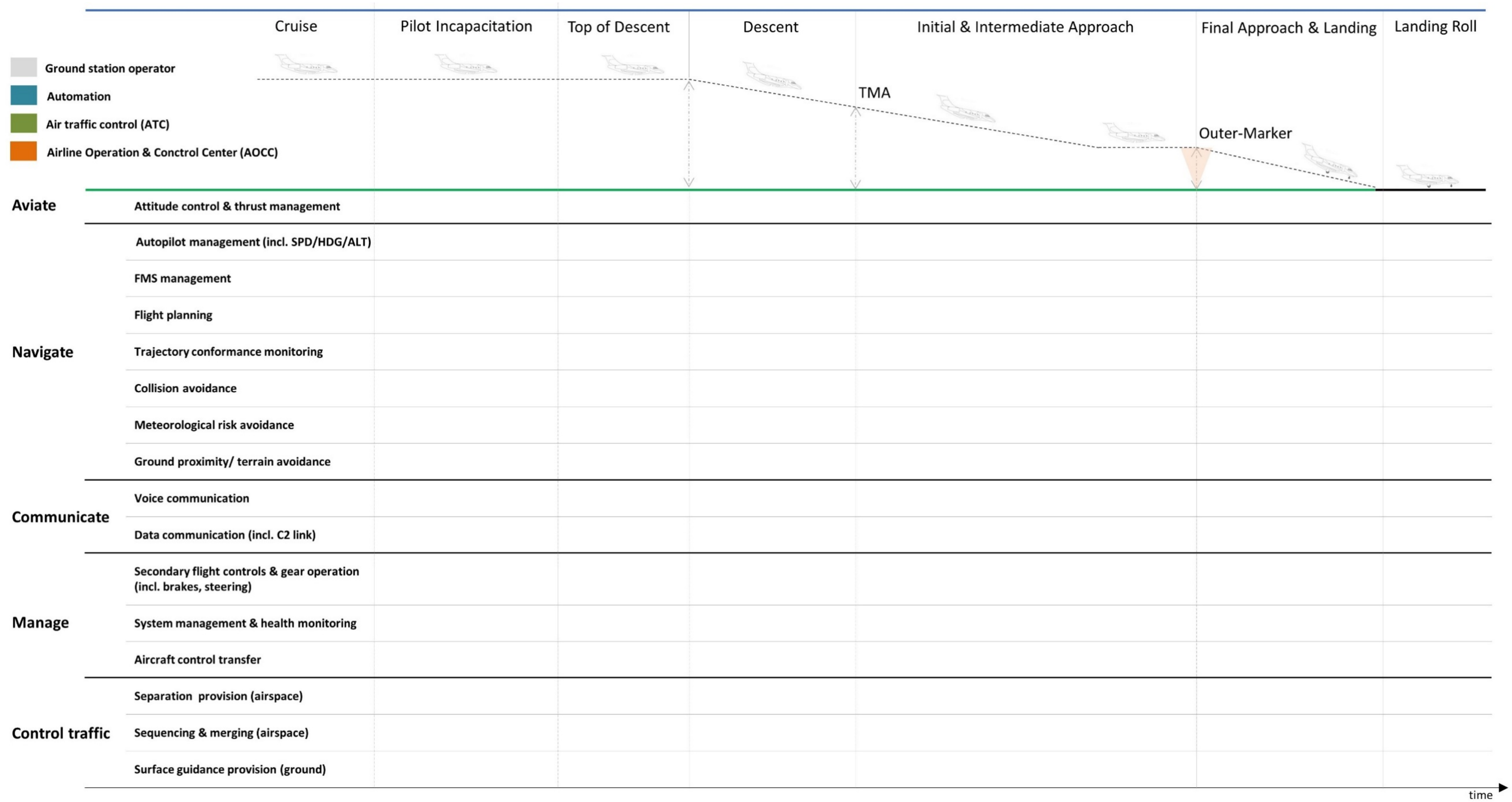


Figure 1. Function allocation template

Physical Function	Description
Attitude	Controlling the aircraft attitude.
Engine thrust	Controlling the engine thrust.
Altitude	Controlling the aircraft altitude.
Speed	Controlling the aircraft speed.
Heading & track	Controlling the aircraft heading and track.
FMS	Managing the flight management system.
Flight Planning	Conducting the flight planning consisting of trajectory generation and trajectory exchange.
Meteorological risk avoidance	Avoiding zones with potentially hazardous meteorological conditions.
Ground proximity/ terrain avoidance	Avoiding collision with the terrain (SJU, 2020b).
Collision avoidance	Mid-air: Avoiding collisions with other mobile airborne vehicles (SJU, 2020b). Ground: Preventing aircraft collision during taxi or push-back (including collisions with parked aircraft) or on the runway or while one is on the ground and the other in the air close to the ground (SJU, 2020b).
Trajectory conformance	Assuring that the aircraft follows the intended trajectory.
Separation provision (airspace; excl. weather hazard zones)	Separating aircraft when airborne in line with the separation minima defined in the airspace design (SJU, 2020b).
Self-separation	Separating own aircraft from surrounding traffic (SJU, 2020b).
Sequencing & merging	Sequencing and merging of departing aircraft as well as sequencing and merging for arriving aircraft.
Surface guidance provision	The ability to provide guidance to aircraft and other vehicles moving on the surface of an aerodrome (SJU, 2020b).

ATC communication	Communicating with air traffic control (ATC).
AOCC communication	Communicating with the airline operations and control center (AOCC).
Visual information	Acquiring visual information from the “out of the window view”.
Aircraft System Management	Managing the aircraft systems (e.g. autopilot, ECAM/EICAS or over-head panel).
System Health Monitoring	Monitoring aircraft system availability and health.
Pilot Health Monitoring	Monitoring pilot mental and physical health.

Table 2. Functions used in the function allocation diagrams.

2.3 Operation Event Sequence Diagram (OESD)

Function Allocation techniques, such as the SOCA-CAT, are a good and established way of describing allocation of functions in a system on a high level. However, they fail to provide insight into the interactions of the involved actors that are necessary to achieve the purposes of the functions. That said, a technique is needed that provides this detailed insight. The method chosen for SAFELAND is the Operational Event Sequence Diagram (OESD). An OESDs can give a basic yet thorough premise whereupon allocation of work can be evaluated with regards to the work process. OESDs illustrate and describe the interactions between operators and artefacts of a system and facilitate the comparison between alternative activity allocations and system configurations. The output of an OESD is a sequence of operational events and task processes over time that are depicted using a standardized set of symbols.

Even though the different phases or sequence of events to be considered for the OESD were not provided in advance to each group, in order to allow a direct comparison between the different variants of the concept the same sequences are presented in this document. They are: Pilot Incapacitation, Handover, Airport Selection and Emergency Descent & Landing.

Table 3 shows the symbols and their respective meanings. It is worth noting that for the SAFELAND initial concept workshop, the symbols were slightly altered to best serve the purposes of the workshop. For a complete description of the OESD method and the original symbols please refer to Harris, Stanton & Starr (2015).

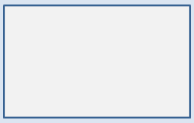
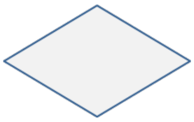
Symbol	Meaning
	Process or Task
	Decision
	Display
	Manual operation
	Speech communication
	Data communication
	Connector

Table 3. Symbols used in OESDs.

2.4 Framework of the workshop

A concept generation workshop, initially planned to be a physical meeting, has been transformed into an online event. Changes in the agenda and the tools used have been made to ensure maximum involvement and effectiveness of the event, even if held in a remote way.

2.4.1 Objectives

The main objective of the workshop was to draft the three different variants of an initial SAFELAND concept for the situation of a pilot incapacitation in SPO in order to land an aircraft safely. Hereby, the workshop participants re-assigned the functions and responsibilities previously identified in D1.1 between the involved entities (i.e. ATC, AOCC, GS and automation) and described the interactions between these entities after the incapacitation has occurred. In order to explore different alternatives of the system configuration, each variant had a different focus as to who is mainly controlling the aircraft (i.e. focus towards automation, GS or ATC).

2.4.2 Outcomes

The definition of a SAFELAND concept is based on the function allocation and OESD diagrams which were developed during the workshop. The workshop participants re-assigned functions needed to maneuver an aircraft through controlled airspace as well as land it at an airport after single-pilot incapacitation onto the remaining actors ATC, AOCC, GS and the automation. The results were captured in a function allocation diagram (cf. chapter 2.2). The interactions between the remaining actors were described by developing an OESD for the handover phase (incl. pilot incapacitation phase) from the incapacitated pilot to a new actor on ground who is responsible for the aircraft and remote control (until landing) of the aircraft (cf. chapter 0). In addition, as the location of the ground station has significant implications on the concept itself, the workshop participants weighed the advantages and disadvantages of different options for the location of the ground station within the frame of their concept.

To summarize, the high-level outcomes of the workshop were:

1. **Function allocation after the single pilot is incapacitated:** Each group defined which actors would be responsible for the functions when the pilot is not able to execute them anymore. However, each group had a different focus as to who would be mainly responsible for controlling the aircraft (i.e. automation, GS or ATC).

2. **Detailed descriptions of the handover phase interactions:** Each group described what interactions would be expected to happen between the remaining entities after the incapacitation is detected (using OESD).

3. **Detailed descriptions of the interactions between relevant parties during remote control of the aircraft:** Each group described what interactions would be expected to happen in order to land the aircraft safely (using OESD).

4. **Discuss different locations of the ground station:** Each group weighed the advantages and disadvantages of different options for the location of the ground station.

2.4.3 Organisation

In order to develop different variants of an initial SAFELAND concept the consortium conducted an online workshop held on 27th and 28th October 2020 attended by experts from different fields of expertise, such as air traffic controllers, pilots, human factors experts, legal and regulation experts, specialists for air traffic management and aircraft manufacturers. In total, 32 participants attended the workshop where each partner of the consortium had multiple representatives present. Moreover, some members of the SAFELAND Advisory Board participated as well.

The participants were distributed into three groups such that each had at least one representative from each area of expertise. The discussion was led by a group moderator and there was an assigned note taker. Each group had a different focus as to who is mainly responsible for controlling the aircraft:

GROUP Automation: In this group the aircraft was assumed to be highly automated and onboard automation would be able to control the aircraft until it lands safely.

GROUP GS: In this group the ground station operator (GSO) would remotely control the aircraft after the pilot incapacitation.

GROUP ATC: In this group the focus was on the role of ATC and the identification of new tasks and responsibilities that air traffic controllers (ATCO) could have in supporting the GS or automation until the aircraft lands safely.

The workshop alternated plenary sessions to working group sessions (cf. Figure 2Figure 2).

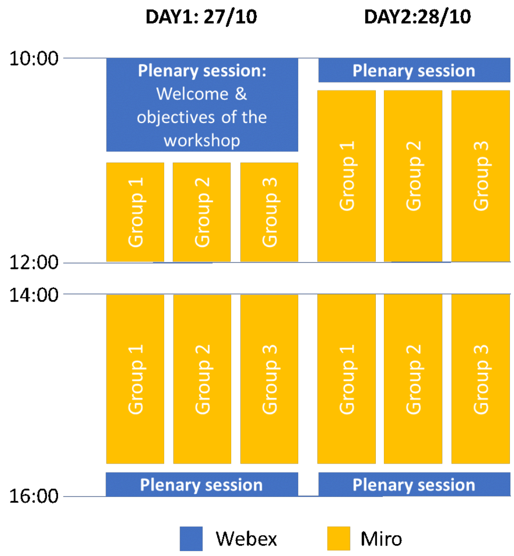


Figure 2. Workshop high-level agenda

The objective of the plenary sessions was to provide objectives and technical support at the beginning of the day and to wrap up and share information at the end of the day. Those sessions were carried out using Webex.

In the **group sessions,** a sub set of participants worked together applying a three steps methodology to generate the functions allocation and the OESD diagrams as well as determine the location of the ground station. The location proposals were enriched by a list of advantages and disadvantages as well as various other considerations. To support this work, an interactive visual tool called Miro was used, allowing participants to directly provide their feedback through e.g. post-its (cf. Figure 3). In each of the groups a group leader facilitated and moderated the discussions while a technical support person managed the interaction with Miro. Additionally, one person per group was assigned to keep the meeting minutes.

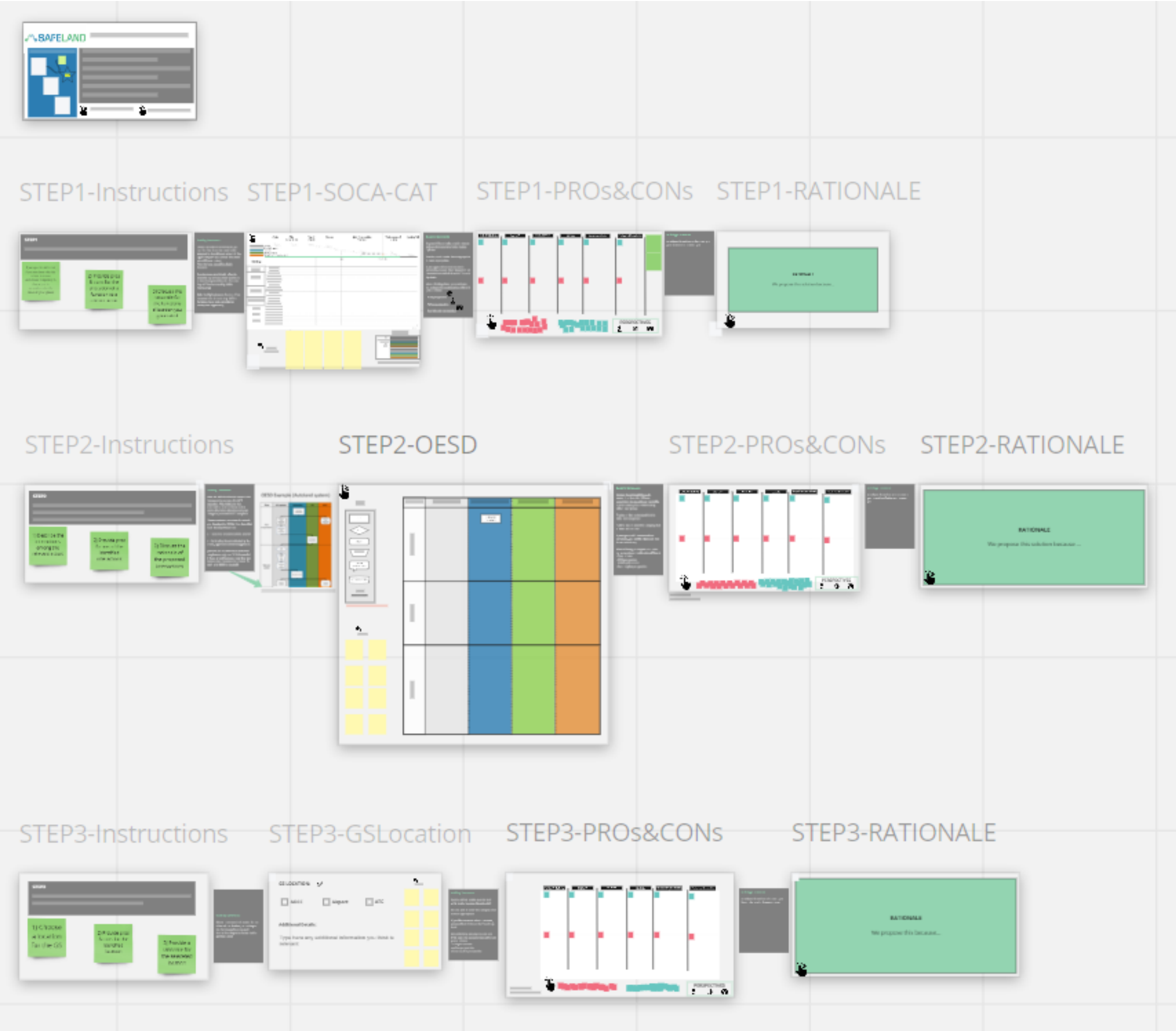


Figure 3. The empty Miro board used to structure and facilitate the concept generation in the working groups

2.4.4 Scoping/ Assumptions

Prior to the workshop the following assumptions and expectation towards the end-system were defined by the workshop participants:

- Nominal flight conditions apart from pilot incapacitation.
- Presence of a ground station that would at least monitor aircraft system and pilot health throughout the flight, operated by a human operator, the Ground Station Operator (GSO). Further, in order to have (financial) advantages compared to dual piloted operations, one GSO is assumed to be monitoring several aircraft at the same time. In an emergency event of one aircraft, the remaining (healthy) aircraft would be transferred to another ground station giving the GSO the opportunity to solely concentrate on the aircraft in need of assistance. The GSO would thus become a dedicated remote pilot for this aircraft.

- The single pilot aircraft is equipped with more sophisticated automation than a current CS-25 certified aircraft (e.g. onboard pilot health monitoring system, reliable and sufficient data link to other actors without latency). Onboard automation is able refuse/reject instructions issued by any human operator from ground if they are outside the performance limits of the aircraft, hence not compliant with aircraft capabilities. In addition, the landing airport supports ILS CAT IIIc approaches, which are currently not operational.
- Presence of an onboard pilot health monitoring system capable of detecting an incapacitation and automatically informing relevant actors. After the pilot incapacitation is detected (and verified), the emergency procedure would be to land the aircraft as soon as possible in order to not put aircraft, pilot and passenger safety at risk.
- The workshop focused solely on total pilot incapacitation.
- To give a frame to the discussion, we assume a 2-3 hours flight en-route over Europe in which the pilot incapacitation occurs during cruise. The rationale for this assumption was that due to its accumulated duration compared to the departure and landing phases, the cruise phase is the most probable phase in flight for a pilot incapacitation to occur.
- Reliable C2 datalink communication throughout all flight phases (incl. no datalink failure/ loss due to areas without coverage)

It is worth noting that the presented assumptions were defined solely for the workshop and to be used in D1.2. Deliverable D1.4 *Final SAFELAND Concept* will not necessarily rely on these assumptions.

2.4.5 Participants

Participants were selected within the project consortium in order to include in each group all the needed knowledge and expertise from the following fields:

- Technical and operational (pilots and controllers)
- Safety
- HF
- Regulation and liability
- Certification

Group ATC

Organisation	Name	Expertise	Role
ECTL	Laurence Rognin	HF	Group leader
ECTL	Pascal Marx	ATCO	
DLR	Ana Martins	HF	
STASA	Yari Franciosa	Pilot	
EASN	Kyriaki Panagopoulou	Dissemination, Marketing	
EuroUSC IT	Pasquale Junior Capasso	RPAS, Certification/ Regulation	
DBL	Aurora Vizioli	HF	Meeting Minutes
LFV	Rickard Jörgensen	ATM Safety, ATC	
EUI	Galileo Sartor	Legal issues	
EMB	Roberto	HF	

DBL	Stefano Bonelli	HF & Safety	Facilitator

Group Ground Station (GS)

Organisation	Name	Expertise	Role
SWISS	Andreas Triska	Pilot	Group leader
DLR	Matthias Wies	Pilot	
LFV	Pim Boonsong	ATC	
ECTL	Caroline Aiglon	Validation Expert	
EuroUSC IT	Marco Ducci	Regulation/ Certification expert	
EUI	Giuseppe Contissa	Legal issues	
DLR	Joonas Lieb	HF	Meeting Minutes
EMB	Marcelo	HF	
EMB	Ney	Systems	
DBL	Laura Moens	HF	Facilitator

Group Automation

Organisation	Name	Expertise	Role
EMB	Jose Parizi	Automation	Group leader
EMB	Ricardo Reis	Automation	Group leader
LFV	Martin Christiansson	Validation Expert	
DBL	Alberto Pasquini	HF & Safety	
EUI	Franceso Godano	Legal issues	
EuroUSC IT	Costantino Senatore	ATC/ ATM expert	
DLR	Thomas Dautermann	Pilot	
ECTL	Aymeric Trzmiel	Validation Expert	
DLR	Max Friedrich	HF	Meeting Minutes
EMB	Thomas	Systems/ Autonomy	
DBL	Daniele Ruscio	HF	Facilitator

3 Initial SAFELAND concept – Group Automation

This chapter presents the initial SAFELAND concept developed by Group Automation during the workshop and later refined. This variant of a concept implies that onboard automation will have the main responsibility of controlling the aircraft after the pilot incapacitation has occurred, while the legal liability of controlling the aircraft will be allocated to the GSO.

As defined in chapter 2.4.4, within this initial concept one GSO is monitoring multiple aircraft and will become a dedicated GSO for the aircraft once the incapacitation is detected by transferring the healthy aircraft to another GSO.

3.1 Function allocation diagram

In general, the objective of this variant of the initial SAFELAND concept is to allocate most of the functions typically done by the onboard single pilot to onboard automation that is more sophisticated than automation available in today´s CS-25 aircraft.

Figure 4 illustrates the allocation of functions developed for this variant, in which onboard automation shall be mainly responsible for controlling the aircraft. At the top of Figure 4 the different flight phases have been added from the occurrence of the pilot incapacitation in cruise (as defined in chapter **Error! Reference source not found.**) until the aircraft lands safely, whereby the flight ends with the landing roll. The left side of the figure depicts the different functions. In total, five high-level functions have been identified (aviate, navigate, communicate, manage and control traffic) to which the detailed functions have been categorized to.

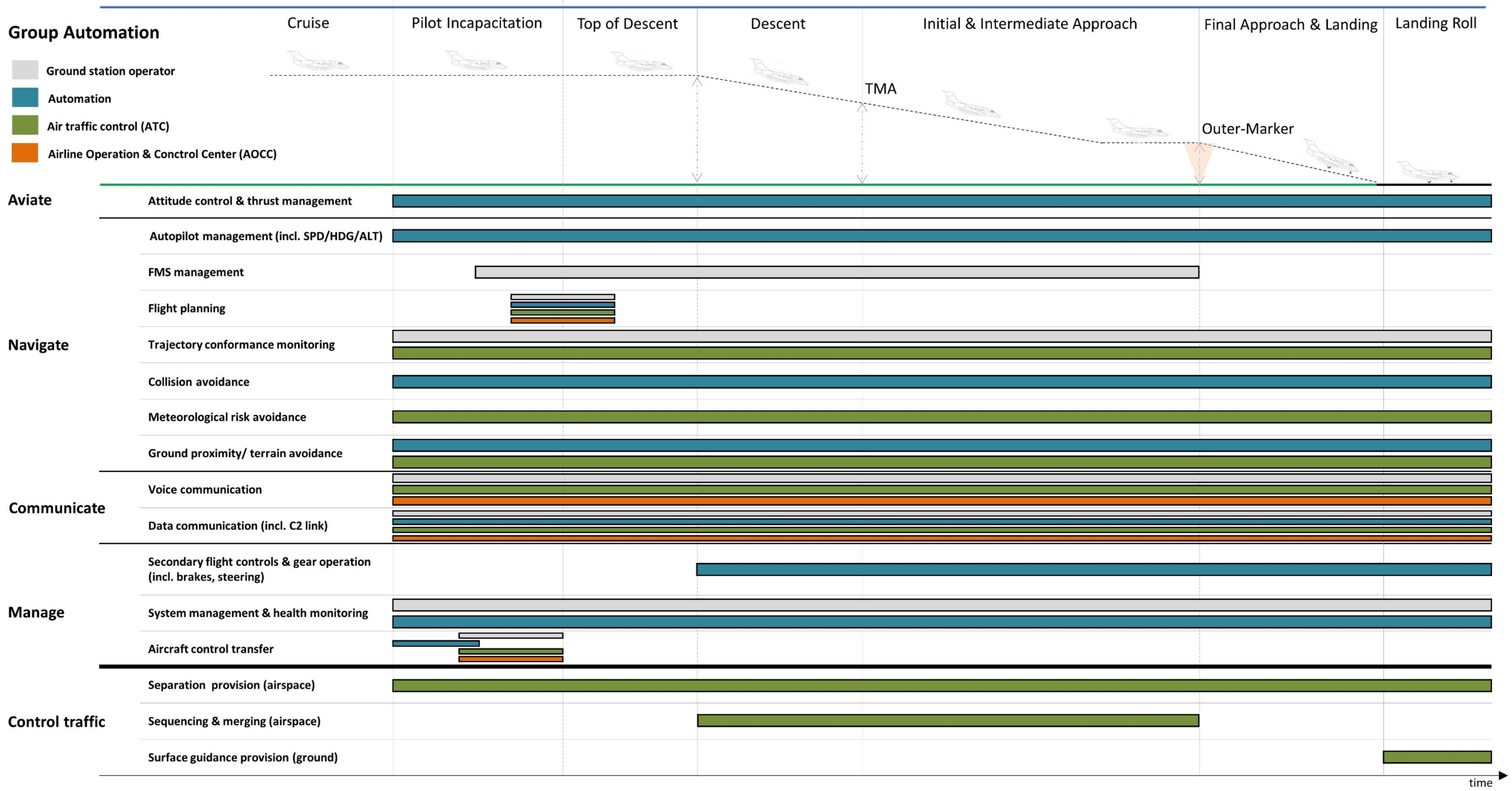


Figure 4. Function allocation diagram developed by Group Automation

The **aviate** function is solely managed and executed by onboard automation, whereby the proposed variant relies on onboard automation capable of, and authorized to, control primary flight controls.

The **navigate** functions are mainly conducted by onboard automation, the GSO and ATC. In a more detailed view, autopilot management and collision avoidance (ground & air) are solely executed by onboard automation. Apart from already existing Traffic Alert and Collision Avoidance System (TCAS) this variant of a concept envisions for the collision avoidance function the operability of more advanced Detect And Avoid (DAA) technology capable of detecting non-cooperative ground and air traffic. In addition, these onboard technologies shall be capable of, and authorized to, manoeuvre the aircraft automatically. Moreover, the autopilot management is foreseen to be conducted by onboard automation as the system is expected to be able to enforce e.g. altitude changes. However, this proposed variant allocates the Flight Management System (FMS) management specifically towards the GSO. It is foreseen that the GSO is able to command the FMS from ground, and onboard automation is able to execute these commands. As detailed in chapter 3.2, the flight planning function including the decision for a new alternate airport involves all four remaining actors (i.e. AOCC, ATC, GSO and automation). Within the trajectory conformance monitoring, meteorological risk avoidance and ground proximity and terrain avoidance function ATC is involved. Especially the meteorological risk avoidance function will be solely executed by ATC as this actor has the global picture of the weather situation (e.g. via METAR, TAF). In addition to ATC, the GSO is also involved in the trajectory conformance monitoring. For instance, constantly monitoring the actual flight trajectory versus the planned flight route is one of the main functions of the GSO in this variant. Similarly, to the collision avoidance function it is expected that advanced DAA technology (as onboard automation) might be able to support ATC in the ground proximity and terrain avoidance function.

Naturally, all actors (i.e. ATC, AOCC, GSO and automation) are involved in the **communicate** functions. On the one hand side, voice communication is a function active throughout the flight, and involves all human actors. As an example, alignment for clearing the concerned aircraft for approaching and landing at or creating a new flight plan to an alternate airport could be foreseen to be performed via voice (e.g. via landline) between the ground actors. On the other hand, data communication involves apart from the human actors also onboard automation. Here, for instance, the exchange of a pilot incapacitation notification via CPDLC messages from an onboard system to the actors on ground could be envisioned. Likewise, the flight plan could be updated using CPDLC.

In addition to the onboard automation, the role of the GSO becomes more central within the **manage** functions. However, first the secondary flight controls shall be managed solely by the onboard automation. As an example, during the descent and landing phase the aircraft flaps shall be deflected automatically to the required flap position (i.e. position 1, 2 or 3). In future, onboard technology might also be capable of keeping the front wheel of the aircraft on the centreline of the runway, and automatically steer the aircraft (e.g. via camera recognition of run- & taxiway). In contrast to the secondary flight controls, the aircraft systems shall be managed from the ground, as well as by onboard automation which shall be able to manage particular aircraft systems automatically (e.g. inner wing and outer tank fuel balancing). For the aircraft control transfer function all actors have to be involved. The GSO will take the responsibility for controlling the aircraft, whereby the onboard automation is executing the defined flight plan stored in the FMS. Moreover, ATC and AOCC will have to be informed of the responsibility having been transferred from the onboard single pilot to the GSO on ground. Hereafter, a new flight plan to an alternate airport has to be generated where all human actors have to contribute to (cf. Figure 5, airport selection phase). AOCC proposes a new flight plan, ATC acknowledge the proposal and the GSO configures the FMS according to this proposed new flight plan.

The **control traffic** function refers to the management of other air traffic within the airspace by ATC. This function does not solely target the aircraft in the emergency situation, but also air traffic in the vicinity of the aircraft with the incapacitated pilot. Hereby, the three functions separation provision, sequencing and merging as well as surface guidance provision are within the responsibility of ATC. The function sequencing and merging can be ensured e.g. by strategical trajectory management and/or flight planning.

3.2 Interaction diagram based on Operational Event Sequence Diagram (OESD)

Interaction diagram based on Operational Event Sequence Diagram (OESD) illustrates the developed interaction diagram using the OESD methodology for the variant of the initial SAFELAND concept where the main tasks for controlling the aircraft in case of pilot incapacitation shall be allocated to onboard automation. The involved actors are depicted at the very top of Interaction diagram based on Operational Event Sequence Diagram (OESD). The left side of the figure shows the different flight phases.

The proposed interaction diagram starts with the occurrence of the **pilot incapacitation** in SPO during cruise. At first, onboard automation (e.g. pilot health monitoring system) is detecting the pilot´s incapacitation. As described in chapter 2.4.4, the concept assumes the presence of more sophisticated automation in future CS-25 aircraft operated as single piloted aircraft. Immediately after the incapacitation is detected, the onboard automation disables the onboard controls within the cockpit in order to prevent any undesirable piloting by the incapacitated pilot. As a result, the autopilot will be engaged, and the aircraft is flying according to the defined flight plan stored in the FMS. Simultaneously the onboard automation transmits notification of pilot´s incapacitation to the remaining actors (i.e. ATC, AOCC and GSO). As an example, it could be foreseen that a predefined squawk code is used for this kind of an emergency. All these tasks are performed automatically by the onboard automation in a timely manner. Hereafter, the informed actors are starting to build situation awareness of the entire situation for themselves.

In the **handover** phase the authority of controlling the aircraft shall be allocated to one of the remaining actors. However, as authority has a legal dimension and is connected with liability it cannot be transferred to a machine (or automation) today, or in the near future (a detailed discussion will be provided in chapter 3.4). In consequence, this proposed variant transfers the responsibility of controlling the aircraft to the GSO, who becomes the Pilot In Command (PIC). As such, the GSO will evolve from his/her monitoring to a more active role within this concept. Therefore, the GSO will handover the unaffected aircraft under his/her monitoring to other GSO, and focus entirely on the aircraft in this emergency situation. Hereafter, the GSO will specifically gain situation awareness of this aircraft by e.g. verifying the aircraft´s position, altitude, distance to other air traffic and aircraft system parameters. After having gained the global picture of the situation, the GSO will announce his legal responsibility for controlling the aircraft to the other actors (i.e. ATC and AOCC), which they will confirm. In parallel, ATC is obliged to clear the path for the aircraft in emergency after having received the notification of pilot incapacitation.

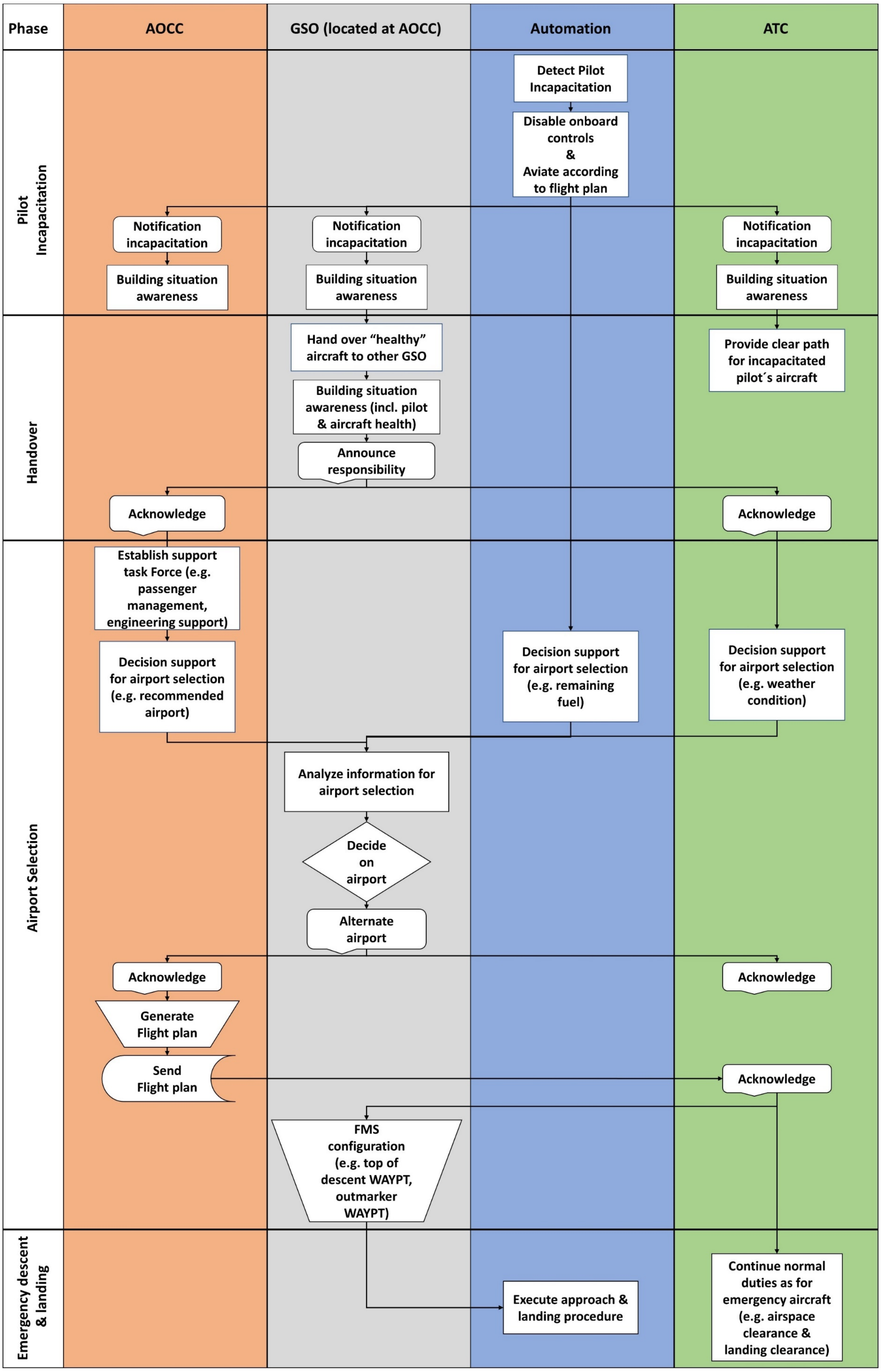


Figure 5. Interaction diagram developed by Group Automation

After the handover phase has been completed the key assignment is to select an alternate airport (**airport selection**) for an emergency landing as soon as possible. However, in this phase, the aircraft is still in cruise altitude. Moreover, from hereon after, all non-critical flight tasks will be conducted by AOCC, whereby ATC, GSO and automation are expected to ensure the safe landing of this aircraft. As an example, AOCC will establish an emergency task force for taking care of passenger management or engineering support. The decision for an alternate airport will be taken solely by the GSO in order to encounter liability concerns. However, for being able to conclude comprehensible on an alternate airport, the GSO relies on the information provided by the other actors. For instance, ATC might be able to provide weather information for a certain airport and AOCC might be able to provide information regarding airline specific considerations (e.g. maintenance capabilities at an airport). Information received from the onboard automation (e.g. remaining fuel) will heavily influence the decision as well. The GSO will analyse the provided information, decide for an alternate airport, and announce the decision to ATC and AOCC. Both actors will confirm the reception of the decision made by GSO. Hereafter, AOCC will create a new flight plan to the agreed alternate airport which will be acknowledged by ATC, and then send to the GSO. As required, the GSO will configure the onboard FMS remotely by transmitting commands (e.g. Top of Descent waypoint) to the aircraft whereby the execution of these commands will be done automatically by the onboard automation. This leads to entering the final phase.

During this final phase the proposed variant envisions a highly automated **emergency descent and landing** automation capable of safely descending, approaching and landing the aircraft to the alternate airport without any additional commands from ground. Hereby, it is assumed that the provided new flight route (from the airport selection phase) entails all the required information for the onboard automation system to proceed and conduct this emergency landing procedure (e.g. outer-marker waypoint). As it is performed nowadays, ATC has the responsibility to e.g. clear the airspace for the emergency landing manoeuvre and to provide landing clearance throughout this phase. It is worth noting, that within this final phase this variant does not foresee the involvement of AOCC.

3.3 Location of the Ground Station

3.3.1 AOCC

In order to identify where the foreseen GS should ideally be located at, the main roles and responsibilities for the GS should be analysed. Within the proposed variant the main roles for the GSO are derived on the one hand from the function allocation diagram, and on the other from the interaction diagram. To summarize the main responsibilities for the GSO can be identified as:

- Inherit authority over the aircraft including legal responsibility in case of pilot incapacitation. In consequence, the GSO is effectively the “new” PIC.
- Decide for an alternate airport based on the information provided by the remaining actors
- Configure remotely the onboard emergency descent and landing automation based on the information received from ATC, AOCC, and aircraft systems
- Coordinate communication – when necessary – with ATC and AOCC

Taking the aforementioned consideration into account, the most suitable location for the GS concludes at AOCC. The AOCC is the place that congregates the largest amount of information and personnel with knowledge of the specific aircraft and its operations. Thus, the GSO would have direct access to this information with minimal delay, and is capable of taking well-justified decision. In addition, the liability remains with the airliner as the GSO would be (most likely) an airline employee. In consequence, each airline would have multiple GS operational within their AOCC facility, where specialized GSO would be monitoring the airline fleet. Moreover, each GSO should have obtained a specific license and training for each aircraft type comparable to a type-rating.

3.3.2 Other options

Potential other locations for the GS have been analysed as well. For instance, the GS could be located at ATC. On the one hand, this option might lead to liability concerns as ATC is not an airline entity and therefore does not appertain to airline authorities. Moreover, ATCs role as an independent entity without the ambition of profit maximization should remain inviolate. On the other hand, reliable, quick and fast access to AOCC knowledge and expertise e.g. via AOCC situation room as nowadays would not be guaranteed. Additional communication means especially resilient against cyber-security threats would have to be introduced.

Another potential location for the GS could be at the airport itself. However, this option would bear high economical risks as a GS would have to be established at (nearly) each airport where a CS-25 certified aircraft permitted to land. Potential advantages of this option, as for instance the line-of-sight between GSO and aircraft in the final landing phase, might be encountered by HD camera technology assembled at the aircraft fuselage and streamed to the GS location. In the end, the high economical costs determine this option as unappealing for the future.

The most promising other option might be a remote facility exclusively dedicated for the operations of aircraft by a GSO. Hereby specialized GSO would work together in one facility able to exchange experiences, know-how and knowledge. Each GSO would have a type rating for the aircraft s/he is supervising, and experienced GSO could support newcomers. Further, GSO of multiple airlines could be located at one facility in order to reduce the costs for commissioning and operate a GS per airline. However, direct access and information exchange to other airline employees (especially from AOCC) would be neglected.

3.4 Conclusion and Discussion

Starting from the radical objective to develop a variant of the initial SAFELAND concept in case of pilot incapacitation for SPO where onboard automation is mainly responsible for controlling and landing the aircraft safely a novel distribution of aircraft function as well as interaction diagram between the involved actors has been presented. Clearly, a minimal diversion from today´s processes, procedures and interactions within the ATM framework in handling an aircraft with an incapacitated pilot would foster the successful implementation of any newly developed concept. In consequence, the proposed variant of a concept intends to change the role of key actors (e.g. ATC) as little as possible.

The allocation of functions (cf. Figure 4) illustrates the necessity for highly advanced and more sophisticated onboard automation compared to today´s CS-25 aircraft capable of maintaining and ensuring the flight envelop and flight safety throughout all flight phases. Within the proposed variant the aviate function is solely conducted by automation. On the one hand, this variant would lead to a "single point of failure" approach where in case of a malfunction of the onboard automation no intervention from ground is foreseen. On the other hand, the onboard automation should not only be capable of receiving and executing commands (e.g. heading change) transmitted from ground, but also have the ability to assess certain flight situation (e.g. cross wind), and react accordingly. Moreover, advanced DAA systems able to provide collision avoidance by detecting crossing air and ground vehicle as well as executing an evasive manoeuvre would have to be integrated, and operational available.

As flight authority respectively, liability for the aircraft cannot entirely be transferred to automation the interaction diagram (cf. Figure 5) concludes the role of the GSO as pivotal despite the attempt to transfer as much responsibility as possible to onboard automation within this variant (this conclusion will be further discussed in the paragraphs). Hereby the GSO takes the role of the PIC, and becomes responsible for the aircraft where the legal liability remains at the airline. As nowadays, and in order to not increase the workload unnecessarily all non-flight critical tasks and administrative activities (e.g. passenger management) will be offloaded to AOCC. Further, the role of ATC does not change compared to today´s emergency procedures. Thereby, airspace clearance is one of the main tasks for ATC. However, the proposed variant implies the existence of an autoland system capable of executing landing procedures starting in the Terminal Area (TMA) of the airport based on predefined flight plans received from GSO in advance.

Table 4 presents the key advantages and disadvantages of the proposed variant of a concept developed by Group Automation.

	Advantages	Disadvantages
Operational	• Initial costs for sophisticated onboard automation as well commissioning of GS can be compensated due to less pilot expenses in the long term • High level of onboard automation requires less GSOs for the airline fleet (one GSO supervises multiple aircraft simultaneously)	• Defined KPIs for support systems may limit operations to certain scenarios/airports • Flight authority must be transferred to a human operator (here GSO)
Safety	• Advanced onboard technology (e.g. DAA) will enhance the safety of flight operations	• Cyber-security concerns must be considered, and solved • Need for robust and reliable onboard automation system • In the aviate function automation is envisioned to be the single point solution within this concept. Therefore, it is single-failure solution
Human Factors	• Enforcing defined procedure to follow on landing eases implementation and detect of	• Need for transparent decisions by automation

	deviations - handling abnormalities • Concept ensures fast communication across actors	• Social acceptance might not be guaranteed
Legal	• Clear liability allocation (here GSO respectively airline) • Clear responsibility allocation	• NIL
Regulation/ Certification	• Certification may limit liability risks	• Single point solution for aviate function bear regulatory risks • High costs for certification of future SPO aircraft with this level of automation • Highly detailed procedures may be too rigid • Means of compliance for safety assurance: how
Technical feasibility	• Envisioned future automation able to handle all flight phases	• High costs for onboard equipment/ automation (e.g. advanced DAA)

Table 4. Key advantages and disadvantages for the proposed concept identified in Group Automation

Within the proposed variant where the main responsibility shall be given to onboard automation there are two key elements that have to be considered:

1. Level of automation
2. Flight authority

As described in the aforementioned paragraphs more sophisticated automation will have to be developed to path the way for SPO where onboard automation is designed to ensure the aircraft´s flight envelope, and in consequence flight safety as proposed in this variant. In many previous works, different scales have been developed to ascertain the **level of automation** of system, relating the level of action and authority that human and machine have. The current state of the art regarding understanding on levels of automation can be referred to the work done in SESAR, defining a Level Of Automation Taxonomy (LOAT) (Save & Feuerberg, 2012). Building upon breakthrough work of Sheridan and Verplank in 1978 (Sheridan & Verplank, 1978) and Parasurman, Sheridan and Wickes in 2020 (Parasurman, Sheridan & Wickens, 2020), a separation is made between different phases of human information processing: acquisition, analysis, decision, action (cf. Figure 6).

Supported function

Level of automation		A INFORMATION ACQUISITION		B INFORMATION ANALYSIS		C DECISION AND ACTION SELECTION		D ACTION IMPLEMENTATION
Done by humans	A0	Manually	B0	Manually	C0	Manually	D0	Manually
	A1	Supported by artefact	B1	Supported by artefact	C1	Supported by artefact	D1	Supported by artefact
Supported by automation	A2	With user filtering and highlighting of relevant info	B2	On user request	C2	With user choice and acceptance among proposals	D2	With user activation & control on actions
	A3	With user control of filtering and highlighting criteria	B3	On user request with alerting mechanism	C3	With user acceptance of one proposal	D3	With user activation and control on action sequence
	A4	With user awareness of filtering and highlighting criteria	B4	With user setting of alerting parameters			D4	With user activation, monitoring and interruption of action sequence
	A5	With filtering and highlighting criteria not visible to the user	B5	With alerting parameters not visible to the user				
Done by automation					C4	With user Informed	D5	With user monitoring, modification or Interruption capabilities
					C5*	With user informed on request	D6	With user monitoring and interruption capabilities
					C6*	With user not informed	D7	With limited user monitoring and interruption capabilities
						** Always connected to Action Implementation D5-D8*	D8	With no user monitoring nor interruption capabilities

Figure 6. LOAT from SESAR[1]

In the last level of automation (D8), there is no path for the human to take part in any of the process phases. Thus, the machine does everything and cannot be interfered. This definition is closely coupled with the concept of autonomy. An autonomous machine is regarded as able to operate and decide by itself in new, unprogrammed scenarios. A fully automated machine can be, or not, autonomous. SAFELAND premises that fully autonomous systems in the aviation domain are beyond the expected time horizon of SPO entering into service. As such, this capability is not considered.

As we are still far from being able to assign full authority to machines, it is a fact that the airplane can be in a situation where flight safety is compromised. An example would be that during the incapacitation event the pilot accidently activates its inceptors (yoke or side-stick, pedals, thrust) and brings the aircraft to a dangerous flight position (e.g., steep descent, stall, etc). In this situation, flight safety is paramount, and an automated system should takeover, to stabilize the situation before a catastrophic outcome (cf. Figure 5, incapacitation phase). Similar technologies and procedures already exist today, like the TCAS – Traffic Collision Avoidance System[2] - or the AutoGCAS – Auto Ground

[1] Table from https://dsaroadmap.org/loat/

[2] https://pt.wikipedia.org/wiki/TCAS

Collision Avoidance System[3]. Thus, comparable onboard systems can be envisioned to be operational for the aforementioned event in future SPO CS-25 aircraft.

However, as fully automated systems can only work in pre-defined scopes, their use and deployment must be carefully considered so they enhance safety and not create blind spots, by being applied beyond their envelope. In this regard, there is need to cater for human supervision and, even, ability to interfere if needed technically or legally. Therefore, the role of a GSO is pivotal in this variant.

The other important key element of this variant relates with liability concerns and the transfer of authority for the flight. Nowadays, **flight authority** is given to the flight captain (i.e. PIC). In an SPO operation, if the pilot is incapacitated, s/he can no longer captain the aircraft. As authority has a legal dimension it is connected with liability. Further, authority cannot be assigned to a machine today or in the near future (i.e., machines are not liable, they have no volition). According to the provisions of the Chicago Convention, the pilot-in-command shall have the final authority as to the disposition of the aircraft (ICAO Annex 2, sec. 2.4 - Authority of pilot-in-command, 2005), and will also bear the "ultimate" responsibility for the operation of the aircraft (ICAO Annex 2, sec. 2.3.1 - Responsibility of pilot-in-command, 2005). The Rules of the Air therefore describe a scenario where the authority is retained by a human agent, that for the purpose of our discussion is assumed to be a professional pilot holding a valid airline transport pilot's license (ATPL)[4]. Authority must thus be transferred to the ground. The most likely candidate is the GSO as the role of the other actors should be affected as little as possible by any new concept. In addition, the GSO is the human "nearest" to the aircraft decision loop as s/he has the situation awareness of the flight. In consequence, the responsibility for controlling the aircraft was given to the GSO within the proposed variant of a concept.

---

[3] https://www.lockheedmartin.com/en-us/products/autogcas.html

[4] According to EU laws, EU-OPS 1, detailed in Commission Regulation (EC) No 859/2008, the final authority is assigned to a qualified pilot (the commander) (OPS 1.090 - Authority of the commander), that may delegate conduct of the flight only to another qualified commander or pilot (Appendix 1 to OPS 1.940 - In-flight relief of flight crew members). Therefore, given the current legal framework, a complete transfer of the final authority to a machine is impossible (or at least, it would create a very high legal risk). However, rules may establish a duty for the pilot to follow instructions issued by a machine (i.e. TCAS II MOPS, namely EUROCAE ED-143/RTCA DO-185B), or (in the future) completely delegate the execution of such instructions to a machine (i.e. the future ACAS Xu, designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres).

4 Initial SAFELAND concept – Group GS

This chapter presents the variant of the initial SAFELAND concept developed by the Ground Station (GS) group during the workshop. This variant implies that a Ground Station Operator (GSO) will have the main responsibility for the navigation of the aircraft after a single-pilot incapacitation has occurred. Hereby, the main duties of remotely controlling the aircraft shall be given to the GS, while the other actors (e.g. ATC, AOCC) are still active and continuously provide necessary assistance to the GSO.

As defined in chapter 2.4.4, within this variant one GSO is monitoring multiple aircraft and will become a dedicated remote pilot for the aircraft once the incapacitation is detected by transferring the healthy aircraft to another GSO.

4.1 Function allocation diagram

This section presents the function allocation in case of pilot incapacitation in SPO when the GSO shall take the main responsibility for remotely controlling the aircraft.

Figure 7 starts with the situation of pilot incapacitation in a single piloted aircraft. The initial SAFELAND concept assumes the presence of an onboard technology (i.e. automation) that is able to detect the pilot incapacitation, and to inform the involved actors. Within this variant, the Ground Station Operator (GSO) now takes the leading role in landing the aircraft safely.

During the workshop, the Ground Station (GS) group decided to initially start with the high-level functions aviate, navigate, communicate, manage and control traffic. Nowadays pilots normally strictly follow the “FLY-NAV-COM” principle. “Fly” (**aviate**) includes the attitude of the aircraft and the thrust management. “Nav” (**navigate**) comprises the questions (i) “Where I am?”, and (ii) “Where do I want to go?”. Moreover, “Com” (**communicate**), means communication to various stakeholders, mainly ATC, Cabin Crew and Passengers, but also to the Airline Operations Control Center (AOCC). The **manage** function includes the aircraft system health monitoring and management as well as autopilot management including speed (incl. trend vector), altitude and vertical speed management. It has to be noted that most of the time the use of autopilot (AP) and autothrottle is feasible and recommended. Therefore autopilot management, and also FMS management plays nowadays a big role in a modern airliner. Finally, the **control traffic** function refers to management of other air traffic by ATC that are in the near vicinity of the incapacitated pilot´s aircraft.

As shown in Figure 7, the variant of the initial SAFELAND concept with focus on GS assumes that onboard automation is capable of changing attitude and thrust values according to a programmed flight plan (or AP) by controlling automatically e.g. primary flight controls and hereby executing the **aviate** function. This is illustrated by the blue box (i.e. allocation to automation) within the aviate function.

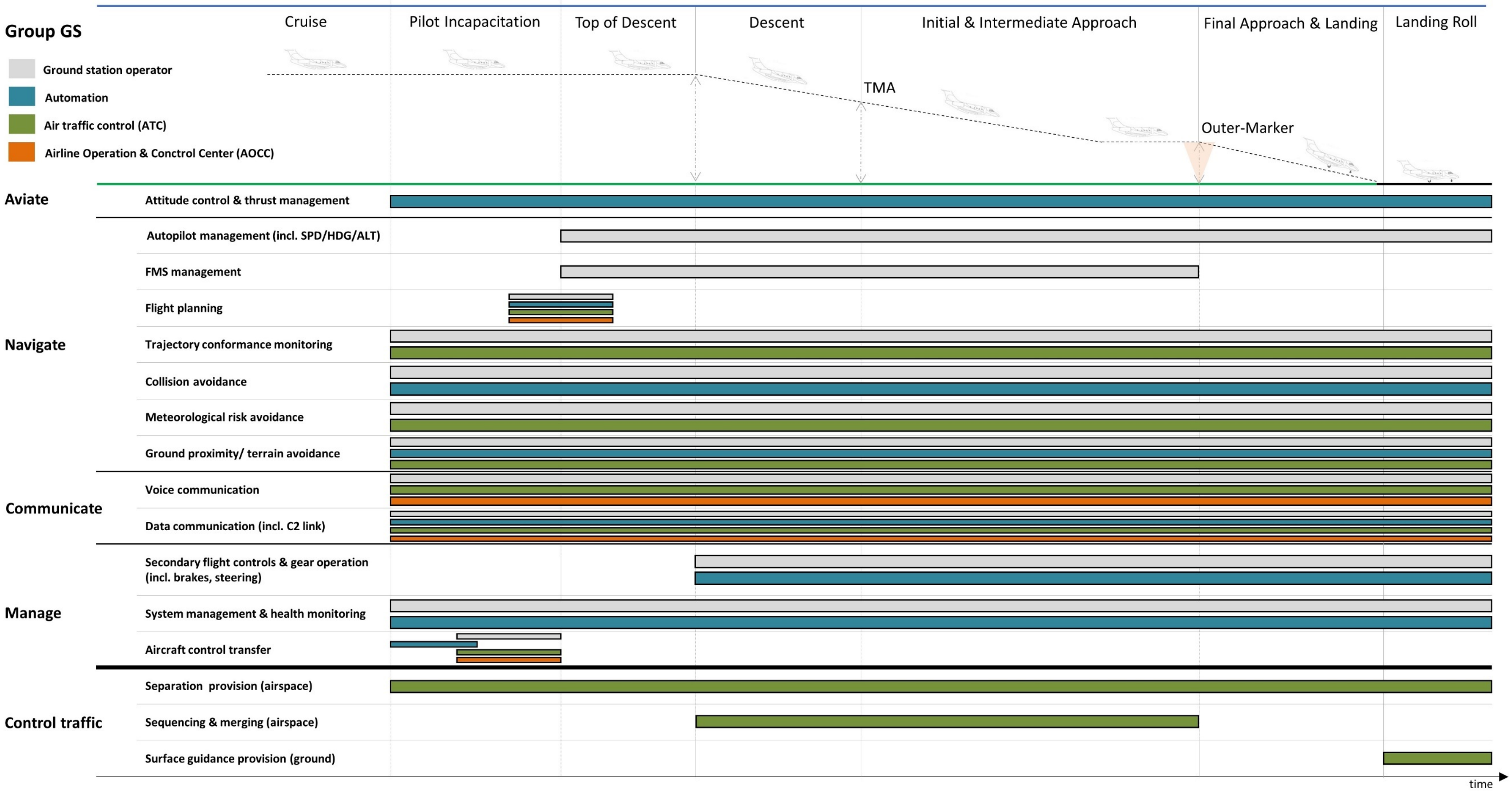


Figure 7. Function allocation diagram developed by Group GS

The **navigate** functions involve all four actors, whereby distinction between the navigate and aviate function is sometimes fuzzy. For this function allocation diagram, autopilot management as well as Flight Management System (FMS) management are primarily considered for controlling the aircraft, but the input and check happens via the Ground Station. These functions are commanded by the GSO, and executed by onboard automation (grey boxes). The flight planning function plays a vital role in single pilot incapacitation, as the GSO has to decide on how to further proceed. The most urgent and important task is to decide on an alternate airport for landing. For this task, several factors have to be taken into account, such as remaining fuel, distance and flight time to alternate airports, weather at destination and en-route, approach aids and runway length at alternate airports as well as, to a certain degree, the preferences of the AOCC. ATC will offer advice and help regarding weather en-route and at airports, but the Pilot In Command (PIC), here the GSO, has to decide on an alternate airport and is liable for his/her decision. Finally, automation will provide specific aircraft system parameters (e.g. current aircraft weight) to foster this decision. Therefore, the flight planning function has been allocated to all remaining actors (i.e. GSO, ATC, AOCC and automation). The ground proximity avoidance and terrain avoidance are of high importance as well. In current aircraft operations, the pilots are responsible for terrain avoidance when the aircraft is proceeding on route/airway, and ATC is responsible for terrain avoidance when the aircraft is flying “under vectors” (typically when flying around thunderstorms, or in the approach phase). Whilst the aircraft is operated from ground, there is the problem that there is no outside cockpit view available. This problem could be solved via cameras in the aircraft providing surrounding outside-view. In this case, these cameras could be linked to the GSO (e.g. to the ground station monitors or Virtual Reality glasses worn by the GSO) providing a good overview. Therefore, this concept foresees the involvement of sophisticated onboard automation in the ground proximity and terrain avoidance function in addition to the responsibilities of the GSO and ATC. However, as SAFELAND is aiming to merely propose an operationally feasible concept, the detailed development of future onboard automation is out of scope for the project and will not be examined in the course of this project. The trajectory conformance monitoring and meteorological risk avoidance function is envisioned to be conducted by ATC and the GSO within the proposed variant. Nowadays, weather avoidance is accomplished by the onboard pilots through their weather radar and lookout (especially for avoiding thunderstorms) and information from ATC through their weather radar at airports. The proposed variant envisions the involvement of ATC and GSO in this function. As a remark, ATC will give advice but not command a deviation due to weather. The GSO, together with automation, is responsible for mid-air collision avoidance whereby again more sophisticated onboard DAA might be able to detect other air traffic (also non-cooperative) and initiate an evasive manoeuvre.

All the human actors (i.e. AOCC, ATC and GSO) are involved in the voice **communication** function. This communication could be envisioned e.g. via radio (air to ground and vice versa) or landline (ground to ground). Hereby, voice communication includes (i) “GSO to Cabin Crew and Passengers for information”, (ii) “GSO to Airline Operations Control Center and vice versa” and to a smaller degree between (iii) “ATC and Airline Operations Control Center and vice versa”. Data communication comprises the datalink connection between GS and the aircraft to control the aircraft and between GS and ATC for clearances regarding the flight.

The **manage** funtcion is primarily executed by onboard automation as well as the GSO. Hereby, especially the management of secondary flight controls (incl. gear, brakes and runway steering) are conducted by the GSO and onboard automation. Again, to a certain degree, this variant envisions sophisticated onboard automation capable of operating secondary flight controls (e.g. speed brakes, flaps or landing gear) automatically - without input from the ground. However, the GSO is able to transmitting commands to the onboard automation operating the secondary flight controls, and executing the command. It is worth noting, that the use of the thrust reversers, landing gear handle, speedbrake and flap-handle is currently a manual task. Here it needs development in the future to make sure that these tasks can be accomplished from the GSO and/or by the automation. In a similar manner, the aircraft system management and health monitoring is managed by both these actors. Finally, the aircraft control transfer function is conducted by all four actors (cf. chapter 4.2, handover phase). For a short period of time, onboard automation will aviate the aircraft according to the programmed flight plan (or autopilot values) until the GSO takes over the control of the aircraft. Hereby, ATC and AOCC are not actively involved but should be informed in due time as shown in Figure 8.

As described in chapter 3.1 the **control traffic** function is again solely executed by ATC. To be precise, there is no difference between the two concepts proposed by the Group Automation and Group GS.

4.2 Interaction diagram based on Operational Event Sequence Diagram (OESD)

This section describes the foreseen interactions between the involved actors ATC, GSO, AOCC and automation, once a single-pilot incapacitation has been detected. The main responsibility for controlling aircraft lies with the dedicated GSO.

The Operational Event Sequence Diagram (OESD) (cf. Figure 8) aims at describing the interactions between the involved actors. During the workshop, the Group GS decided to work with a “Top-Down” approach (starting from the pilot incapacitation phase and ending with the landing phase) and the aim was to keep the events and sequences as simple and congruent as possible. Afterwards, the OESD was refined.

Figure 8 begins with **pilot incapacitation** phase. First, an onboard system (i.e. automation) detects the pilot incapacitation. Immediately hereafter, the onboard controls will be disabled in order to prevent any unintended input by the incapacitated pilot and for a short period of time, the autopilot and auto thrust take over the duty of aviating the aircraft. Simultaneously, the onboard automation sends out a notification of the incapacitation to the GSO, who in turn informs ATC and AOCC (e.g. via voice communication). Both actors confirm the reception of the announcement, and can already start to prepare for the emergency event.

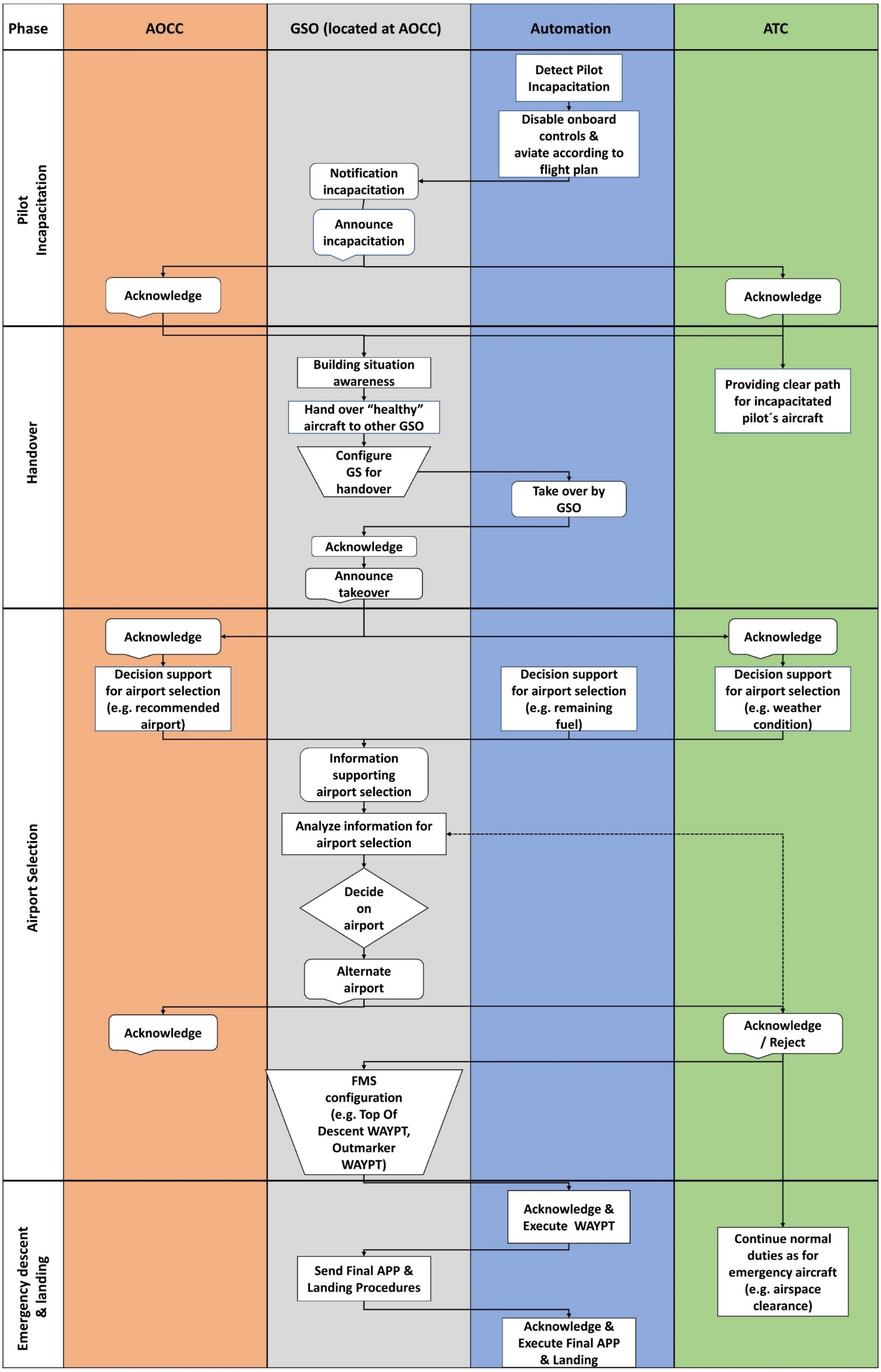


Figure 8. Interaction diagram developed by Group GS.

Entering the **handover** phase, the GSO builds up situation awareness e.g. by checking aircraft system parameters, and initiates the handover process. As an example, the GSO is configuring the GS application in a way that s/he is able to send commands to the onboard automation of the aircraft. Additionally, this GSO will become a dedicated operator exclusively responsible for the aircraft in the emergency situation. Other aircraft will be transferred to another GSO. The GSO takes over the duty of controlling the aircraft from the automation. Automation acknowledges the handover and is able to receive commands from the GS. Hereafter, an announcement of the handover will be sent to ATC and to AOCC. These actors confirm the handover. It should be noted that the handover method could not be defined at this stage and would have to be investigated further. The group, however, discussed the probabilities of a one-click solution and code exchanging.

In the next phase, the **airport selection** for an immediate emergency landing procedure will take place. Automation, ATC and AOCC will provide information for selecting the most suitable landing airport to the GSO. After analysing this information, the GSO takes the decision for a landing airport, whereby the decision is his/her responsibility. This decision will be announced to ATC and AOCC. However, ATC will still have the option to object to this decision, e.g. if the weather conditions change severely. After the alternate airport has been confirmed by ATC, the GSO will start to enter the alternate airport parameters into the FMS.

Hereby we enter the **emergency descent and landing** phase. As it is done nowadays, ATC has the duty of e.g. clearing the airspace for the landing procedures of the aircraft in this emergency situation. Moreover, these duties entail providing terrain and traffic awareness as well as separation and clearing the aircraft for a straight in landing approach. In consequence, other aircraft approaching or taking off from the airport may be delayed. Finally, the onboard automation will execute the emergency descent, approach and landing procedures upon the commands send by the GSO to the aircraft. In detail, onboard automation will acknowledge and execute the planned flight route received from ground as well as follow the final approach and landing procedures commanded by the GSO.

As the group worked through the interaction diagram, it became evident that in most cases it is recommended that with one “push message” all stakeholders (i.e. ATC and AOCC) will be informed about the same information at the same time (e.g. the decision for the alternate airport) by the GSO.

It has to be noted, that after the successful handover by the GSO this variant of the initial SAFELAND concept does not entail many differences compared to emergency procedures conducted in today’s airline operations. As the most critical phases, the successful detection of the pilot incapacitation by the onboard automation as well as the handover phase have been identified. Within this variant, all involved actors may feel some time pressure, as rapid landing increases the chances of the incapacitated pilot to survive. However, of utmost importance is the safe landing of the aircraft, and hereby the well-being of the passengers.

4.3 Location of the Ground Station

The Group GS identified two different options as suitable locations for the GS. On the one hand, bigger airliners might wish to keep the GS facility in-house, most likely at the AOCC (cf. chapter 4.3.1). On the other hand, smaller airliners might wish to outsource this part of their operations to a specialised company (e.g. external provider) in order to reduce costs (cf. chapter 4.3.2).

4.3.1 AOCC

From an airline operational point of view, the GSO located within the AOCC (e.g. dedicated department within the AOCC building) bears the potential to be close to other airline operation entities and supporting departments. Hereby a close communication line and a fast decision-making process will be ensured. Especially, the short distance to important stakeholder as e.g. Dispatcher or Airline Network Operations Control is favourable. Moreover, the AOCC facility is deemed to be located in a secured area (i.e. restricted area of the airport), and thereby secured against unauthorized access. In addition, by locating the GS at AOCC the GSO will remain an airline employee. In consequence, the liability of controlling the aircraft remains within the airline company. Last but not least, a GS located within the AOCC facility is more likely to be accredited and certified by national and international authorities as its operation remains within the airline oversight and responsibility. In practice, the Group GS foresees that multiple specialized GSO monitor and supervise the fleet of an airline within AOCC. Most likely the GSO would have to obtain a specific type-certificate for each aircraft type (comparable to pilot licenses ATPL) including a “type rating” for remote operations. Similar to todays continued education of pilots, recurrent trainings and refresh courses for GSO have to be provided and documented to ensure competencies. The GS interface could be seen as mock-up of a single pilot aircraft (e.g. generic cockpit simulator) representative for different aircraft types.

However, a GS located at AOCC might not be cost beneficial for smaller airlines as they might only operate one or two aircraft from one aircraft type for which they would need specialized GSOs each. Here an outsourced facility operated by an external provider which offers the GSO services to smaller airlines might be an option (cf. chapter 4.3.2).

4.3.2 Other options

The Group GS also discussed the implication of a different location for the GS on the proposed variant, namely an outsourced facility. This facility could be organised in two different ways:

1. The GSOs in the facility are working for different airlines or
2. The GSOs belong to one airline, and the employees are together located in one dedicated facility.

For option 1 a joint cooperation between airlines might be fruitful for the GSOs, as well as for the airlines as an exchange of knowledge, lessons learned and experiences can be expected. Moreover, a joint facility would be more likely to be cost efficient for smaller airlines as investments would be shared. In both options support from GSO specialists to less experienced GSO could be realised. However, an outsourced facility requires massive initial investments from the airlines or operator of the facility.

Other options as e.g. GS at the airport were not deemed as feasible as they would require a GS at each airport. Furthermore, line of sight for the GSO to the aircraft was not deemed a necessity as pilots are nowadays landing aircraft with nearly no outside view (e.g. Runway Visual Range of 200 Meter for a CAT IIIa approach). In the future more sophisticated automation might be able to land an aircraft without human intervention.

4.4 Conclusion and Discussion

During the establishment of the new operational concept, the group realised that a simple to use procedure bears the most advantages. In addition, the group´s intention was to deviate from current function allocation, procedures and interactions as little as possible. Taking these high-level aims into account, the variant of the initial SAFELAND concept where the main responsibility for landing the aircraft safely has been appointed to a GSO relies on an allocation of aviate and manage functions as well as partially on an allocation of navigate functions to the GSO. A more detailed view on the function allocation has been provided in Figure 7, and will be discussed hereafter.

The **aviate** functions are expected to be commanded by the GSO and executed onboard automation. This expectation assumes the presences of more sophisticated automation. Within the **navigate** function the allocation towards ATC does not change from today´s operation, and AOCC is only involved in the flight planning. This is important for the acceptance of the proposed variant by the aviation community as the workload for ATC and AOCC will remain on the same level. Obviously, the GSO will be involved in the navigation functions that have been accomplished by the onboard pilot prior to his/her incapacitation. However, this additional workload to the GSO will be compensated by the fact, that this variant envisions the involvement of a dedicated GSO solely responsible for the aircraft within the emergency situation. Naturally, the **communication** function implies a shared allocation between all actors, which is comparable to nowadays operation. Within the **manage** function only the function *aircraft control transfer* required the involvement of ATC and AOCC. Hereby this variant of a concept ensures limited additional workload to these actors in order to increase the potential of implementing the variant into the existing ATM framework. The other manage functions will be solely commanded by the GSO, and executed by onboard automation or be automatically executed by more sophisticated onboard automation. The **control traffic** function is entirely managed by ATC. However, within this function there are no additional tasks foreseen to be conducted by ATC compared to nowadays. Based on the proposed function allocation this variant does not increase the workload of current ground operators (i.e. ATC or AOCC operators).

For the interaction in case of pilot incapacitation in SPO Figure 8 presents the envisioned communication between the main stakeholders within this variant. On the one hand, the detection of the pilot incapacitation, as well as the handover phase heavily rely on a system or automation that has to be invented, which is easy to understand, to follow and keeps all involved actors in the loop in a timely manner. In consequence, the proposed variant of a concept assumes that future technology will enable the invention of state-of-the-art detection and handover systems. In particular this will be addressed in section 6.2.4.

Moreover, as the involvement of a GSO to the ATM framework is new, but pivotal for this variant, novel processes and procedures have to be developed, tested and certified for this role. Especially, the task of deciding on the alternate airport is a key element within this variant and shall be appointed to the GSO. In addition, configuring the GS in order to being able to send commands to the onboard automation as well as building up situation awareness are two additional tasks for the GSO. Here, support from the other actors is crucial. However, the already existing information exchange between aviation entities (e.g. ATC and AOCC) could be extended easily by one additional stakeholder (i.e. GSO).

On the other hand, however, the role of ATC in this variant of a concept is mainly to support the GSO by e.g. clearing the airspace for a rapid approach and landing process. Hereby, the variant envisions the role of ATC mainly as it is today. Moreover, the role of the AOCC will not differ from today operation. Providing information for the decision of an alternate airport is a responsibility AOCC is familiar with. This variant can rely on the processes and procedures already in place as the current course of actions proved its reliability and safeness over years.

One key element for ensuring safe aviation in airline operations is to provide a "shared mental model" between the involved actors. Therefore, the proposed variant foresees the distribution of information to all involved actors. This does not necessarily mean that the information has to be provided at the same time, but at least timely to all stakeholders. Moreover, the way of the distribution from the ground station to the other partners has to be kept simple and in a short spell e.g. via voice communication. As a result, the interaction diagram shows a clear structured procedure with timely involvement of all stakeholders.

Last but not least, it has to be ensured that the workload is manageable and fairly distributed amongst the actors in order to maintain present safety margins or increase them. There are still humans at work, although we can imagine that at the time of the introduction of this procedure the support by computers, Artificial Intelligence (AI) and machine learning will have greatly increased. Therefore, this variant aimed to limit the workload especially for ATC and AOCC operators.

However, some points are naturally still open for discussion within this variant. For example, the question when ATC has to be informed of the occurrence of the pilot incapacitation. There are advantages and disadvantages for different approaches: (1) Informing ATC at the time of detection has the advantage that ATC is in the loop as soon as possible, but bears the possible option of a false warning. (2) If the information is passed on to ATC, once the incapacitation is confirmed by the GSO (as currently shown in Figure 8), ATC will immediately respond to the ground station operator, but at this stage the GSO might be busy taking over the control. Finally, if we consider the third possibility, which is (3) the information will be sent to ATC once the handover phase is completed, then ATC may already suffer a time delay for clearing the nearby airspace. This should only give an example how complex these decisions are and as a result, these points shall be further examined in WP1, and concluded in D1.4 *Final Concept*.

In order to assess the proposed variant Table 5 presents its key advantages and disadvantages in more detail.

	Advantages	Disadvantages
Operational	• Likely to be accepted by society supposing a GSO has required competence. • No additional costs for airlines, as the initial costs like creating infrastructure, certification or training for the GS can be compensated by the reduction of onboard pilots	• Still unclear how manual tasks (gear, flaps, etc.) can be operated from Ground Station and/or automation. • Obstacle, terrain and weather awareness require the GSO to have outside view (e.g. via camera)
Safety	• The function allocation diagram can lead to the assumption that the current level of safety can be	• NIL

	maintained, however a detailed assessment is required • Workload for GSO seems feasible • GSO ensures the fulfilment of the "four eyes principle" in aviation by monitoring the flight	
Human Factors	• It will be very important to define a clear and systematic working method (list of tasks, order of execution, assignment of actors responsible of tasks) similar to "Checklists" nowadays. • Ability to build confidence in system/procedure from general public, passengers, airlines ANSP and authority, as all stakeholder continue to work according their expertise and it is transparent. • Possibility for pilots to work on a GS with certain medical limitations (e.g. problems with pressure equalization)	• Required skills and training to be set up for the GSO. • If there are not so many differences in procedures compared to today it means that GSO skills have to be maintained as onboard pilot ones, not just a system operator
Legal	• Possible for GSOs to have multiple licenses • Regarding responsibility the allocation of key functions (e.g. separation, FMS management) is clear • Liability is clear as the GSO acts as PIC	• Unclear if GSO has to be airline employee
Regulation/ Certification	• Likely to be certified/approved than other concepts (put the right person on the right task)	• GS needs to be certified as part of the aircraft Type Certificate process with potentially high costs. In fact, any equipment contributing to the aircraft airworthiness must undergo a certification process.
Technical feasibility	• No significant change at ATM the level with respect to the current situation • No major technical "showstoppers" if taking workshop assumptions into account (e.g. data reliability) • No significant change from current ATC system architecture (e.g. Data Link or Radio Communication can still be used for communication between GSO and ATC and vice versa).	• Cyber security issues • Assumptions like datalink capabilities and reliant automation have to be guaranteed

Table 5. Key advantages and disadvantages for the proposed concept identified in Group GS

As a result, the variant of the initial SAFELAND concept with main responsibility for controlling an aircraft in case of an emergency relying on a GSO is based on three key principles:

First, a Ground Station facility with experienced GSO has to be established at the AOCC. Hereby, the liability for the aircraft remains on the airline, and a direct communication line to airline specific experts is guaranteed. A specific training for the GSO has to be established with a type certificate for different aircraft types. It is recommended, to rely on former and active pilots with an ATPL as GSO, especially at the beginning of integrated GSO into the existing ATM infrastructure.

Second, the proposed variant relies (highly) on advanced onboard automation in SPO which are not available in today's airline fleets. On the one hand, onboard automation is expected to able to execute commands received from the GSO via datalink. Especially, the aviate function relies on this functionality. Hence, aircraft controls that are nowadays operated manually (e.g. speed brakes or gear) will have to be able to be executed in an automated manner from ground by bypassing the mechanical locks. On the other hand, new technology such as a pilot health monitoring system are needed to be integrated and operational in a future single pilot aircraft. Further, a secure and reliable data link between ground and air including minimal latency are pivotal for this concept.

Third, communication processes to the new actor (i.e. the GSO) have to be introduced and agreed on. An operational checklist for handling pilot incapacitation situation must be put in place and implemented to ensure smooth coordination between involved actors. However, there is no major change in the ATC procedures compared to dual piloted aircraft in an emergency situation today. ATC is clearing the airspace for the aircraft in the emergency situation, and providing support to the GSO who is acting as the PIC. In addition, the newly developed variant does not anticipate additional workload for the involved actors (i.e. ATC and AOCC) apart from the GSO.

5 Initial SAFELAND concept – Group ATC

This chapter details one of the variants of the SAFELAND concept developed by Group ATC during the workshop. As already explained (cf. 2.4), the focus was on the role of ATC and the identification of new tasks and responsibilities that air traffic controllers could have in supporting the Ground Station or automation until the aircraft lands safely in case of pilot incapacitation of a single piloted aircraft. Interaction with the Airline Operation Control Centre (AOCC) was also considered.

This concept variant implies that ATC is given more responsibilities than in the other two groups. The main goal was to assess if, and how, some of the onboard and remote piloting functions could reasonably be transferred to air traffic controllers, what assumptions would need to be made and how feasible this option could be.

In Groups Automation and GS, the different functions were mainly allocated to automation and the Ground Station Operator (GSO), respectively. In a similar way, in Group ATC it was necessary to allocate the tasks that could not be done by an air traffic controller to automation or to the GS. In some cases, the decision was easy to make based on safety, operational, Human Factors considerations, or even on the required technology. In other cases, it was not possible to reach a definite answer and both options (i.e. transferring tasks that cannot be done by ATCO to automation or GSO) were considered. It should be noted, however, that ATCOs present in the discussion were mostly in favour of transferring responsibilities to the GSO, whereas non-ATCO participants favoured automation. Whichever the case, these distinctions will be mentioned in the sections below.

5.1 Function allocation diagram

This subsection details the function allocation in case of pilot incapacitation in SPO with focus on the ATCO. The actual sequence of events that would take place from the moment incapacitation is confirmed to the aircraft landing safely will be described in section 5.2.

As shown in Figure 9, according to this concept variant, the ATCO handling the aircraft would be able to provide direct commands for speed, vertical rate, heading and altitude to the concerned aircraft, which would require access to the autopilot and the flight management system (FMS) from the ground. However, this was also one point where an agreement between the members of this group was not reached. Some participants (partners with ATCO background) insisted that all instructions given by the ATCO would need to be confirmed by the GSO or the AOCC. Others considered that the ATCO should be able to send the route directly to the aircraft bypassing the confirmation step by the GSO or AOCC, the same way that the ATCOS nowadays are able to send messages to the aircraft via CPDLC. The technical implications of this will be discussed below in section 6.2.4.1.

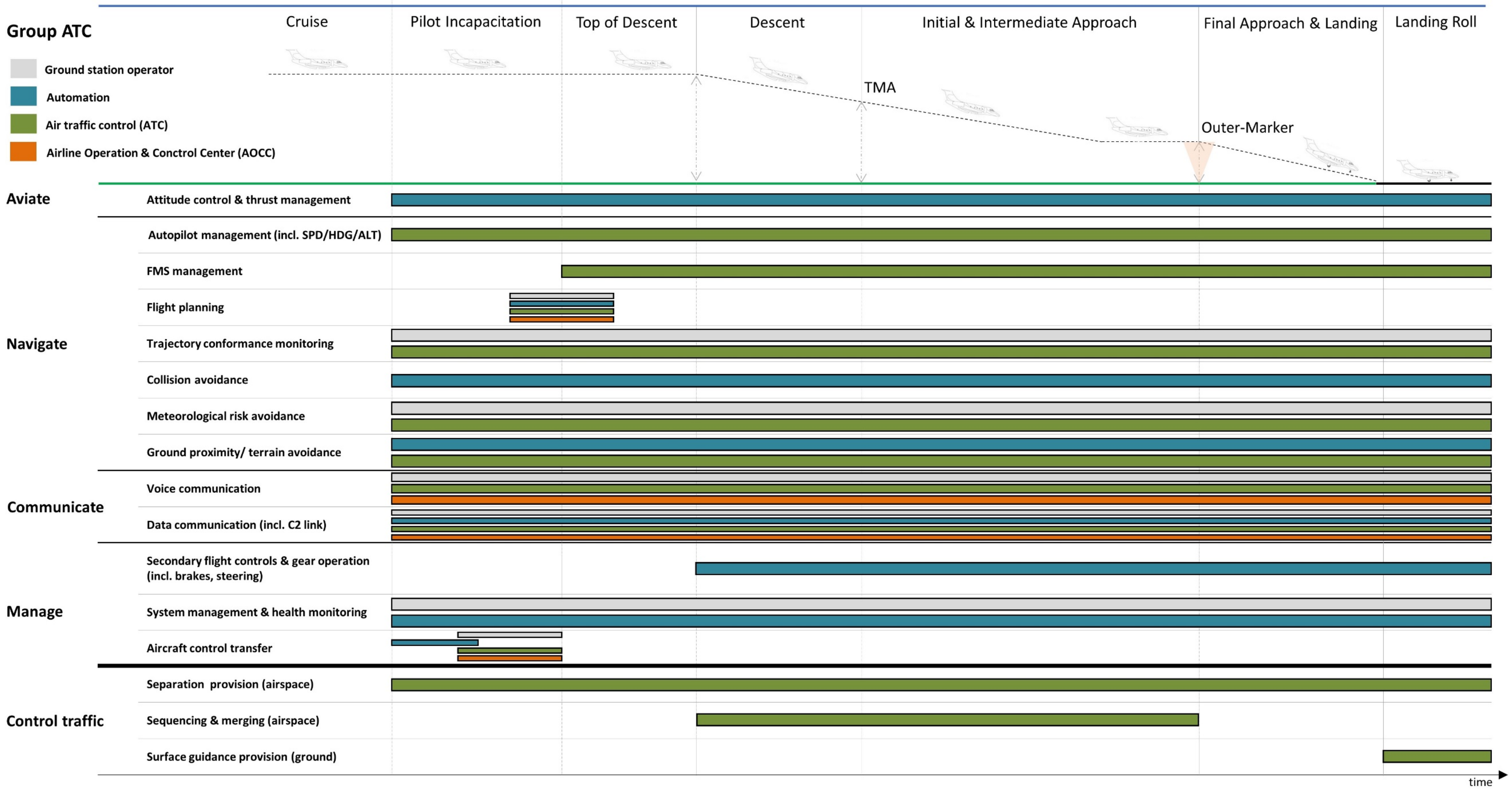


Figure 9. Function allocation diagram developed by Group ATC.

Attitude control and thrust management **(cf. aviate function)** would be executed by automation, as well as the management of secondary flight controls and the operation of the landing gear. Some onboard technology could also support the ATCO, for example, by keeping the front wheel of the aircraft on the centreline of the runway. In a similar manner, the monitoring of aircraft systems and of pilot health would be conducted by onboard automation. Of course, this information is available to the GSO. As stated in section 2.4.4, one of the assumptions in SAFELAND is that with single pilot operations there will always be a ground station manned by an operator (the GSO) who monitors at least that aircraft.

The ATCO would remain responsible for supporting the current functions of ATC like separation provision, sequencing & merging, surface guidance provision **(cf. control traffic function)** once the aircraft lands as well as ground proximity and terrain avoidance (the latter together with automation – as it is the case nowadays with the Ground Proximity Warning System). If there is a risk of an imminent mid-air collision between the concerned aircraft and another aircraft, aircraft automation will follow the indications of the Airborne Collision Avoidance System.

It is expected that the air traffic controller would be the main actor responsible for detecting adverse weather conditions (e.g. based on METAR/TAF data) and sending new headings to the aircraft. However, this should not prevent the GSO from requesting and coordinating a diversion with the ATCO. As in current operations, the ATCO would also be the main actor responsible for monitoring the aircraft trajectory for conformance, with the GSO following the situation as well, as part of his/her responsibilities in normal and emergency situations (cf. **navigation functions**).

The generation of a new trajectory (Flight Planning) once incapacitation is confirmed would be performed by the ATCO after negotiations with the AOCC and the GSO (cf. chapter 5.2 for the actual sequence of events). Note that, as stated above, the ATCO would be the one uploading the new flight plan to the aircraft, but the responsibility for the final decision on where to land the aircraft would remain with the AOCC. Onboard automation would also be able to reject the new route if instructions are not within the aircraft's capabilities. The ATCO would also need to coordinate the new trajectory with at least one other ATCO downstream, since the aircraft might need to cross one or two sectors from the moment the emergency is declared until it lands. In terms of data communication (cf. **communication function**), it is then required that there is a stable and secure data link between all the actors mentioned: automation, the GSO, AOCC and ATC. In addition, it shall be possible for the ATCO to communicate via voice with the GSO when required, for example, to clarify the meaning or the intent of any ambiguous datalink message.

With regards to the transfer of aircraft control (cf. also chapter 5.2) (cf. **manage function**), once incapacitation is confirmed, automation takes control with the main goal of stabilizing the aircraft. Then, based on the decision of where to land the aircraft[5], the ATCO will provide the clearance to get there, with the GSO monitoring the situation. The proposed function allocation relies on two aspects.

- On the one hand, an ATCO being able to support the aircraft in the emergency situation which might require special training for the ATCO. Even though issuing instructions is normal ATCO

[5] Selection of the airport will depend on various factors, out of scope of the project, e.g. distance from initial planned destination, airport category and capability to support landing, emergency status, etc.

work, in the context of incapacitation additional training might be required to support new tasks such as coordination with GSO and with airlines. Nevertheless, an ATCO has the knowledge about the procedures for coordination with adjacent sectors and relevant airports. They can reach the responsible ATCO in the next sector, as well as the emergency teams at the destination airport.

- On the other hand, this proposed allocation of functions is based on a highly automated aircraft able to operate all systems, including those that are currently manually performed (e.g. landing gear deployment, slats and flaps setting, etc.).

5.2 Interaction diagram based on Operational Event Sequence Diagram (OESD)

Figure 10 illustrates the interaction diagram in case of pilot incapacitation for SPO, when considering that the ATCO is able to interact directly with the aircraft (Step 2 of the workshop). As will be explained in section 5.3, at the end of the workshop Group ATC concluded that the best location for the Ground Station would be at the AOCC (Step 3). This has implications on the OESD because it means that the OESD developed in Step 2 did not take into account the chosen location of the GS. Therefore, it was decided that it would be best to present and discuss in this chapter an interaction diagram that already considered the chosen location of the Ground Station in the AOCC.

In total, the following four different phases were considered: detection of pilot incapacitation, handover, airport selection, emergency descent & landing. Figure 10 starts with the detection and confirmation of the **pilot incapacitation** by an onboard pilot health monitoring system (i.e. automation). An emergency system in the aircraft automatically disables onboard controls to prevent those cases in which, for example, the passed-out pilot accidently touches the flight controls and the aircraft leaves its flight envelope. It should be noted, however that as this variant of a concept is assumed to be integrated in an aircraft with fly-by-wire and flight envelope protections, even in manual flight and with an incapacitated pilot no dangerous flight states (e.g. imminent stall, overspeed, overbank, etc.) could be entered. For safety and security reasons, this “passivation” of aircraft controls function might be overridden by the pilot in case of a false alarm[6].

[6] Pilot incapacitation due to terrorist attack/hijacking is out of scope for SAFELAND.

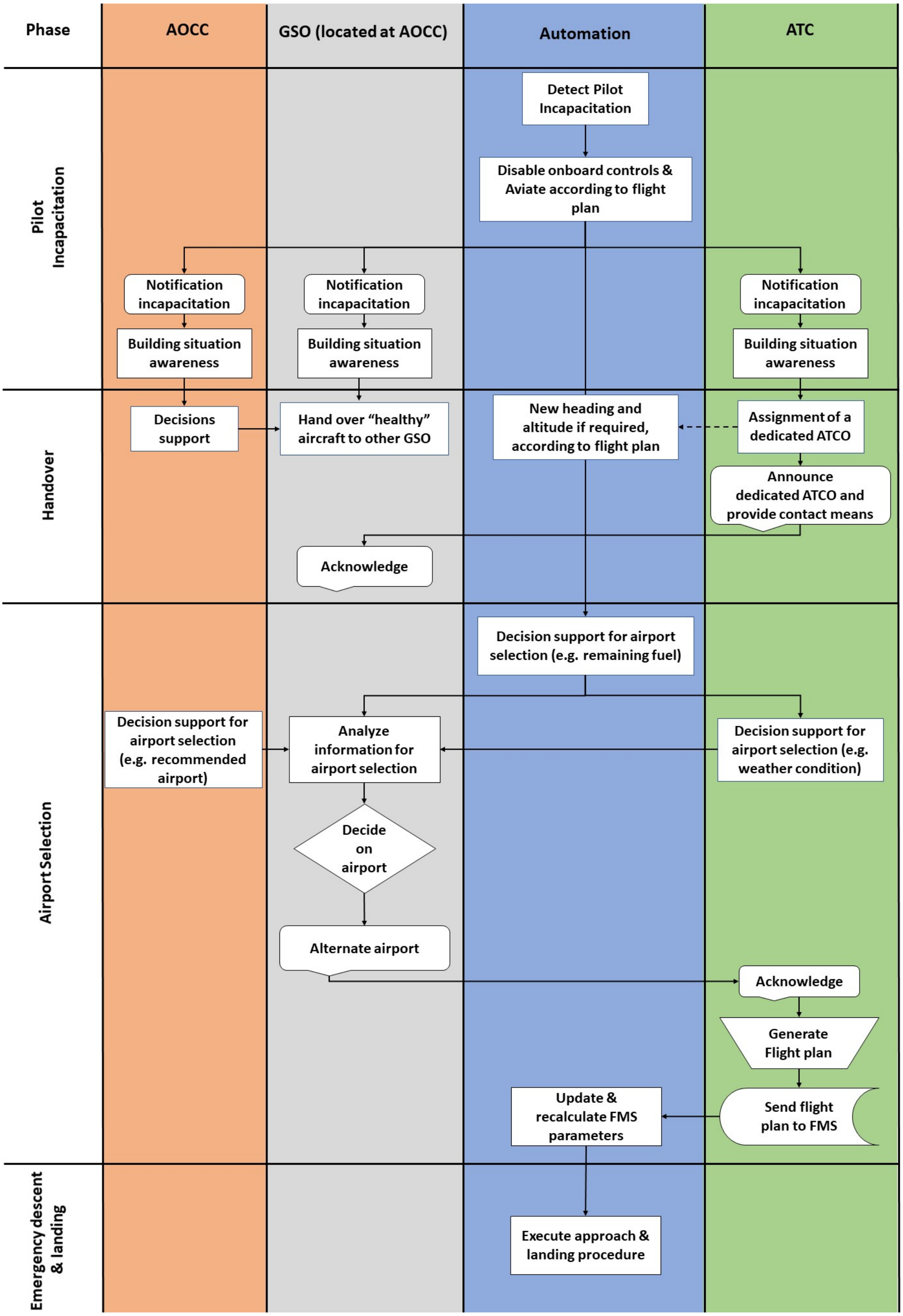


Figure 10. Interaction diagram developed by Group ATC (with the GSO located at AOCC). Prior to the handover this figure reflects the sector ("old") ATCO. Afterwards the dedicated ATCO

The automation also informs the GSO and the ATCO on duty about the pilot incapacitation. The ATCO assesses the situation and attempts to reach the pilot to confirm the incapacitation and ensure it is not a false alarm or failure in the system ("building situation awareness"). The ATCO must also start the standard operating procedures for an aircraft emergency. This includes giving priority to the aircraft (separation provision, sequencing & merging will now be done giving the aircraft in the emergency situation the right-of-way) and alert his/her supervisor, or another designated person. As soon as the emergency situation is confirmed (i.e., ongoing loss of communication with the pilot and evidence that onboard automation is flying the aircraft), the **handover process** is initiated and a dedicated ATCO[7] will be assigned to this aircraft. In other words, the current ("old") ATCO remains in charge of the rest of the traffic in the sector and the new ATCO is dedicated to handling the emergency aircraft. The dedicated ATCO would be briefed by the first ATCO in order to gain situation awareness before starting working. To ensure correct communications and exchanges, this new controller would also be announced and acknowledged by all relevant actors. The possibility was also discussed that a new Controller Working Position would be opened with a new ATCO who would take over the "normal" ATCO duties, whereas the "old" ATCO would become the dedicated ATCO, since s/he would have the best knowledge about the situation (clearances given to all a/c in the vicinity, last known contact with pilot, etc.). Ultimately this would be the ATC supervisor decision, as s/he needs to ensure that the controllers on position are able to perform their tasks (in terms of skills, knowledge, mental/physical state, etc.).

According to this variant, only the dedicated ATCO is allowed to change the route via datalink, no other controller can directly interact with the aircraft and modify the route. If required, as today, the dedicated ATCO is able to send a new heading or altitude to the aircraft until the most suitable airport for landing is chosen.

The GSO and, consequently, the AOCC are also assessing the situation. As stated in section 2.4.4, once the emergency is declared, the GSO would become a dedicated GSO for this aircraft, with a new GSO taking over the monitoring of the other aircraft. Note that with the Ground Station located at the AOCC, it is expected that the GSO would initiate the airline's specific internal procedures to handle aircraft emergencies.

The GSO is now monitoring an aircraft in an emergency situation and performs a quick assessment of the health of all relevant systems (probably through a dedicated checklist). The automation is flying the aircraft according to the flight plan stored in the FMS and, as a backup plan, calculating a suitable airport for landing from an existing database. This database would include all airports with emergency services and suitable for that particular aircraft. This backup plan is required to account for any loss of data link[8] between the aircraft and the ground due to some malfunction or lack of coverage. If there are no failures, the dedicated ATCO is able to immediately provide new clearances to the aircraft (e.g. heading) as needed. In parallel the "normal" ATCO is clearing the traffic.

---

[7] The dedicated ATCO might be a dedicated pair of ATCOs (EC-PC), as it is foreseen that planning controllers might in the near future also issue data link clearances.

[8] As stated in the SAFELAND proposal (SAFELAND Project, 2019), loss of datalink is out of scope. Therefore, this particular event will not be further discussed.

The next step is to **select the airport** for landing. During this phase the onboard system sends subsets of information to each actor (e.g. information about aircraft health status to GS and AOCC). This information will help these actors in deciding the landing airport. It should be mentioned that the workshop participants insisted that the ATCO is not a pilot and therefore should not be expected to perform the tasks of one. This means that the dedicated ATCO will not have access to all data available, but only to the information needed to perform his/her tasks and responsibilities. It is expected that trajectory generation and upload does not require access to other aircraft systems, but security concerns still need to be considered in order to avoid potential new methods for hijacking. If the dedicated ATCO requires more information, it would be provided by the GSO, who has access to other data.

It was decided that mostly for liability reasons, the AOCC through the GSO (who has access to all relevant aircraft parameters, e.g. fuel on board) would be the one proposing the landing airport and making the final decision, with support from the dedicated ATCO, who has access to other relevant information (e.g. weather around the airport, restricted areas, runway conditions, etc.). Once the decision about the airport is made, it is communicated to the dedicated ATCO who can facilitate the execution of the decision (e.g. best way to reach the airport) by generating a trajectory and sending it to the FMS, ensuring a minimum delay for the safety of the pilot and passengers. As already mentioned in section 5.1 this might require coordination with the ATCO from downstream sector. The aircraft automation would then update and recalculate performance parameters and get ready to **execute the approach and landing procedures** upon controllers' instructions.

The question was raised whether the aircraft could be under the responsibility of the same dedicated ATCO from incapacitation to landing if the principle of "landing the aircraft at the nearest suitable airport" is followed. Although this could seem safer and more efficient (e.g. reduced communications and coordination across sectors), this is not feasible in current operations. Indeed, in current air traffic control operations, controllers are trained and licenced to operate not only in a given type of environment (en-route, approach or airport), but also on a specific geographical airspace. Controllers' licence does not only include principles of traffic control, but also knowledge of airspace specificities (e.g. waypoints, restricted areas). As a consequence, a controller will be dedicated to the handling of the incapacitated aircraft in each sector crossed.

The extent of the involvement of the GSO in this variant was not agreed by all members of Group ATC. Some members defended that the GSO should also have the possibility to directly interact with the aircraft to confirm and accept the instructions given by the dedicated ATCO (adding some redundancy to the process), while others considered that only the ATCO should have the possibility to do that, in order to prevent conflicting inputs. This remains an open issue, with further discussion and research being required before a final decision can be reached.

Also note that AOCC has many responsibilities which were not considered nor discussed during the workshop and are therefore not shown in the OESD (Figure 10), as for example, how to get the passengers to their destination. It is assumed that most tasks and responsibilities that are also currently done by AOCC are not expected to change.

5.3 Location of the Ground Station

The function allocation diagram and the OESD were used to support the workshop participants in the final decision on the location of the Ground Station.

5.3.1 AOCC

During the workshop Group ATC decided that the best location for the GS would be at AOCC. From an airline operations' point of view, locating the GS at AOCC would be beneficial as the ground station operators would be airline employees and be familiar with the airline's specific procedures. In addition, the airline would be responsible for education and training, as they do for pilots today. Furthermore, having the GSO at AOCC increases the possibility for faster decision-making (due to short communication lines) which is of the upmost importance in emergency situations. Finally, the liability for the aircraft remains with the airline, as is the case today.

This variant of a concept relies on each airline having one ground station operator monitoring several aircraft and at least another standby operator who would start working in another station in case of an emergency. Note, however, that it might not be necessary to have a dedicated GSO just for this potential emergency situation. In fact, we can probably assume that more than one ground station operator would be working at any given time if the airline has several aircraft flying in single pilot operations. In case of an emergency, the GSO monitoring this aircraft might simply transfer his aircraft to other GSO to reduce his/her workload levels.

5.3.2 Other options

One option which was discussed was to locate the Ground Station at the airport. This makes some sense if we consider that landing is one of the most critical phases from a safety perspective. Therefore, once the emergency is declared the aircraft could be flown to an airport with a GSO who would be familiar with the conditions of the airport (e.g. terrain, weather, runways, airport layout, etc.). The problems with this option are two-fold: first it would require that each airline would have ground stations on each airport they flew to, which economically does not make sense (in fact, the most suitable airport for landing might not even be an airport served by the airline). Second, in this variant of the concept the GSO has mostly a monitoring role, with the ATCO having most of the responsibilities. Therefore, the presence of a Ground Station at the airport would not lead to relevant benefits.

Locating the GS at the Air Traffic Control Centre would also be problematic. Several different airlines would need to have ground stations there to serve their aircraft. Recall that Single Pilot Operations would require some monitoring from the ground during normal operations, therefore this would be standard procedure and not just during an emergency. Air Traffic Control Centres, however, are independent from airlines and work by a completely different set of rules and regulations.

5.4 Conclusion and Discussion

This SAFELAND approach where the air traffic controller has more responsibilities than in current operations, requires the involvement of a dedicated ATCO directly interacting with aircraft automation and a ground operator with monitoring duties located at AOCC and the means to communicate with ATC. In short, automation flies the aircraft following instructions provided by the ATCO, which are checked by the GSO. Some partners insisted, however, that the same way that all ATC clearances issued by the ATCOs in current operations can be accepted or rejected by the pilots, they should also be accepted or rejected by the GSO before being uploaded to the aircraft. Either way, the AOCC is expected to be following the situation through the GSO and provide support on the decision of where to land the aircraft.

This initial SAFELAND variant of the concept is based on two key elements. On the one hand, in each sector a dedicated ATCO shall be designated to the aircraft in the emergency situation. On the other hand, onboard automation shall be able to execute instructions received from ATCO, such as new heading or altitude commands. In the allocation of functions (Figure 9), the ATCO was foreseen to be responsible for main navigation functions such as defining the flight plan, including e.g. speed and altitude commands, while the onboard automation would execute these instructions. This dedicated ATCO would also be able to alert the emergency services at the airport. However, this would possibly lead to unacceptable levels of workload if the controller remains responsible for their more traditional functions like separation provision and conflict avoidance. Therefore, it was necessary to introduce the role of a dedicated ATCO solely responsible for the navigation functions of the emergency aircraft and for coordination with the other ATCOs, the GSO and indirectly with AOCC. Some of the advantages are the fact that the required expertise and processes for decision-making in an emergency situation are partially already available at ATC. However, because of licence issues, the emergency aircraft would not be handled by the same controller from incapacitation occurrence to landing, but by a series of dedicated controllers in each sector crossed.

The main responsibility of the GSO relies on supervision of the aircraft parameters, coordination with AOCC, as well as the assessment of global situation. In the interaction diagram (Figure 10) one key decision shall be taken by the GSO and the AOCC: the decision on where to land the aircraft. This approach ensures that the liability remains within the airline company. Even though ATC is mainly interacting with automation and not with the cockpit crew (as today), the ATCO’s responsibilities do not differ substantially from today´s operations under an emergency situation: ensure separation provision and a conflict-free flight by assigning specified headings, speeds and levels suitable for the planned approach and landing, and then monitor the flight regarding adherence to flight plan.

The most reasonable location for the GS in this variant of the concept is at AOCC. On the one hand, it ensures fast and reliable communication process between the GSO and the airline, which would stay informed of the events throughout the flight. On the other hand, the liability for the aircraft remains on the airline (as it is today).

The proposed variant assumes a more sophisticated automation that can execute all aircraft controls. Moreover, the proposed interaction would imply that additional information would need to be provided to the ATCO compared to today. Furthermore, specific training for the ATCO for this rare event would be necessary.

Error! Reference source not found.Error! Reference source not found. lists the key advantages and disadvantages of this concept variant.

	Advantages	Disadvantages
Operational	• More onboard automation leads to less workload for human operators (hence more support to the ATCO)	• The situation requires a dedicated ATCO handling only the emergency aircraft. • Procedures for handover of control from one ATCO to another must be established

	• ATCO have all knowledge and procedures for coordinating with adjacent sectors and relevant airports.	before the dedicated ATCO starts working
Safety	• More parties involved that can help (ATCO, GSO and AOCC) and more information sharing between aircraft and ground should increase safety • ATCO's overall SA enables the safest decisions to be made (in terms of route to avoid other traffic)	• Higher risk of malicious cyber-attacks targeting the aircraft communication • High level of automation is required to guarantee a good level of safety • Need reliable and secure communication • Need robust and safe automation
Human Factors	• Situation awareness: if the ATCO previously handling traffic sector is the one taking over the task of managing the emergency aircraft, he/she will have a complete awareness of what is happening • If the ATCO can directly interact with the onboard automation there will be less workload (we are saving a lot of the ground station operator/controller communication related workload)	• Additional training for ATCO required • Training: as it is improbable that even a dedicated ATCO would do these types of intervention often, adequate simulations training should be considered • A dedicated endorsement for handling this task might be required. • A lot of information given by different entities must be processed which might lead to confusion
Legal	• Liability remains on the airline through the GSO as he/she is monitoring the situation and may be able to reject commands sent to the aircraft by the ATCO	• More parties being involved; more legal issues in case of problem
Regulation/ Certification	• Introduction of new regulations that can be used in the future for autonomous flight (a first step towards autonomy)	• Increase in regulations and difficulties for certification • Strong requirements in terms of cyber security • Certification of the new aircraft (e.g. aircraft should be certified to CATIIIc) • ATCO needs to be certified if they are taking additional responsibilities • Certification for "autonomous" carriage of people • Increase in regulations and difficulties for certification

Technical feasibility		• Need to develop new aircraft automation technology • Strong requirements in terms of cyber security which have to be solved by new data link capabilities • Requires pan European access to data link • Impact on ATCO system, especially HMI design: Visualization of instructions given to aircraft, and executed by automation need to be developed in a user-friendly way

Table 6. Key advantages and disadvantages for the proposed concept variant identified in Group ATC.

It is worth nothing that within this variant there are some issues regarding liability and responsibility of the involved actors, which shall be addressed in D1.3 in more detail.

6 Discussion

Deliverable D1.2 proposes three variants of an initial SAFELAND concept with three different focuses on who shall be mainly responsible for controlling the aircraft in case of onboard single pilot incapacitation. All three proposed variants of the concept have in common that they aim **to modify current ATM processes, strategies and procedures for an aircraft in an emergency situation as little as possible.** However, Group ATC would require the biggest changes to ATM as described in chapter 5. ICAO Doc 4444 (ICAO, 2016) states the following general ATM rules for any aircraft in emergency (which can be regarded as valid in the SAFELAND context):

- The aircraft receives priority over other aircraft (cf. section 15.1.2 of ICAO Doc 4444]) and in consequence ATC will to the largest extend comply with any requests from this aircraft and take care of separation from the other aircraft.
- Any aircraft in the vicinity shall be made aware of the emergency situation by broadcast from the aircraft in emergency (cf. section 15.2.2.3 ICAO Doc 4444]).

In consequence, the aircraft in emergency has to comply with emergency ATM regulations. The ATC will continue to have its own responsibilities, including ensuring separation of the aircraft in emergency with the other controlled aircraft operating in the same volume of airspace. In other words, **the ATCO is responsible for clearing other aircraft off the "path" of the aircraft in emergency.**

In addition, one of the most important conclusions of the project ACROSS (ACROSS, 2016b) was that in case of crew incapacitation it is vitally important that ATC are supplied with the maximum amount of information about the ongoing status of the flight. Although the Ground Station has all the information, it needs to be clarified how, when and how much of this information should be shared with ATC. Ideally, **ATC should be able to receive the same information as the GS, as long as it is relevant for the ATC's tasks and responsibilities.**

Further, the ICAO Doc 4444 (ICAO, 2016) states that "various circumstances surrounding each emergency situation preclude the establishment of exact detailed procedures to be followed", which in consequence means that, even though SAFELAND will propose operational guidelines to handle incapacitation situations, **it is impossible for SAFELAND to cover every possible situation and predict all decisions that could be made by AOCC, GSO and ATCO**.

6.1 Similarities and differences between the proposed variants

In order to analyse the three variants of a SAFELAND concept, prepared by the three groups Automation, GS and ATC, the key differences and similarities are explored and examined. First, the proposed allocation of functions for each variant will be discussed in 6.1.1. Then, a deeper analysis on the interaction diagrams by focusing on the differences in key elements (e.g. decide airport) will be elaborated in section 6.1.2.

6.1.1 Function allocation diagrams

The developed function allocation diagrams (Figure 4, Figure 7 and Figure 9) show major similarities for all three variants of the concept. As an example, in all cases the **aviate** function would be executed by onboard automation. In addition, the high-level **control traffic** functions (i.e. separation provision, sequencing and merging as well as surface guidance provision) would also continue to be executed by ATC as they are done nowadays. Furthermore, the allocation of the **communicate** functions is identical in each of the variants since it should always involve all actors within the described system.

However, the allocation of the **navigate** functions differ significantly between the variants. Major differences can be identified in the FMS management and autopilot management function as these would be directly commanded by the actors who shall have the main responsibility (i.e. by GSO in Group GS, by automation in Group Automation, by ATCO in Group ATC).

Flight planning (incl. decision of airport to land, trajectory generation and trajectory exchange), however, is a function which relies on the involvement of the same four actors (GSO, Automation, ATCO, and AOCC) in all three variants.

Trajectory conformance monitoring involves the GSO and ATC in all three variants. In addition, the approaches proposed by Groups Automation and ATC rely on onboard automation to perform the mid-air collision avoidance function. Group GS expects the involvement of the GSO in this collision avoidance function in addition to automation.

All three groups expect the ATCO to support the **meteorological risk avoidance** function, but the GSO is also monitoring the situation in Groups ATC and GS, with the possibility to coordinate with ATCO any changes in trajectory.

Moreover, **ground proximity and terrain avoidance** require slightly different involvement of the actors. Groups Automation and ATC propose to involve onboard automation and ATC (provided that controllers have appropriate support tools to perform these tasks), whereas Group GS adds the GSO.

Regarding the **manage** functions in general, all three variants allocate a major role to onboard automation. Both Groups Automation and ATC rely on exactly the same actors to perform the various management sub-functions. That is, automation should control the secondary flight controls and gear operation, and both automation and the GSO monitor the aircraft system management and system health. Whereas Group GS foresees the same actors as Group Automation and Group ATC to perform these functions, it suggests to involve the GSO in the secondary control function as well.

The main differences described above are summarized in Table 7.

Functions		**Group GS**	**Group Automation**	**Group ATC**
Aviate		Automation	Automation	Automation
Navigate	**Autopilot**	GSO	Automation	ATCO
	FMS	GSO	GSO	ATCO
	Flight Planning (i.e. trajectory generation)	All actors	All actors	All actors
	Trajectory Conformance monitoring	GSO & ATCO	GSO & ATCO	GS & ATCO

	Collision Avoid.	GSO & Automation	Automation	Automation
	Meteorological Risk avoidance	GSO & ACTO	ATCO	GSO & ATCO
	Ground Proximity/ terrain avoidance	GSO & Automat. & ATCO	Automation & ATCO	Automation & ATCO
Communication		All actors	All actors	All actors
Manage	**Secondary Flight Control**	GSO & Automation	Automation	Automation
	System Management & Health Monitoring	GSO & Automation	Automation	Automation
Control aircraft	**Separation provision, sequencing and merging, surface guidance provision**	ATCO	ATCO	ATCO

Table 7. Key similarities and differences between the three variants in the function allocation diagrams

6.1.2 Interaction diagrams

The comparison between the developed interaction diagrams (Figure 5, Figure 8 and Figure 10) highlights the need for **sophisticated onboard systems capable of supporting each of the proposed workflows** in case of pilot incapacitation. For instance, having a pilot health monitoring system onboard of the aircraft able to detect pilot incapacitation is pivotal to all three variants. However, as SAFELAND is focusing more specifically on the ground side of the ATM framework, the onboard health monitoring system was assumed, and its operation will not be examined in detail (cf. chapter 6.2.4.1 for more information).

As explained in section 2.3, four phases were considered: Pilot Incapacitation, Handover, Airport Selection and Emergency Descent & Landing. As shown in Figure 11, during the **pilot incapacitation phase**, the interactions in all three proposed variants have major similarities. Assuming that onboard automation would detect the incapacitation, all variants have in common that the aircraft would hereafter disable the onboard controls (e.g. in order to prevent any further accidental manoeuvres by the incapacitated pilot) and aviate according to the current Flight Plan until the aircraft control (i.e. navigate function) is transferred to the GSO (Group GS), automation (Group Automation) or ATCO (Group ATC). Simultaneously, the designated human operators on the ground would be informed by the automation of the incapacitation occurrence. Group GS proposes that the GSO is first notified by automation, and then informs ATC and AOCC. In the other variants, automation would inform simultaneously all human actors.

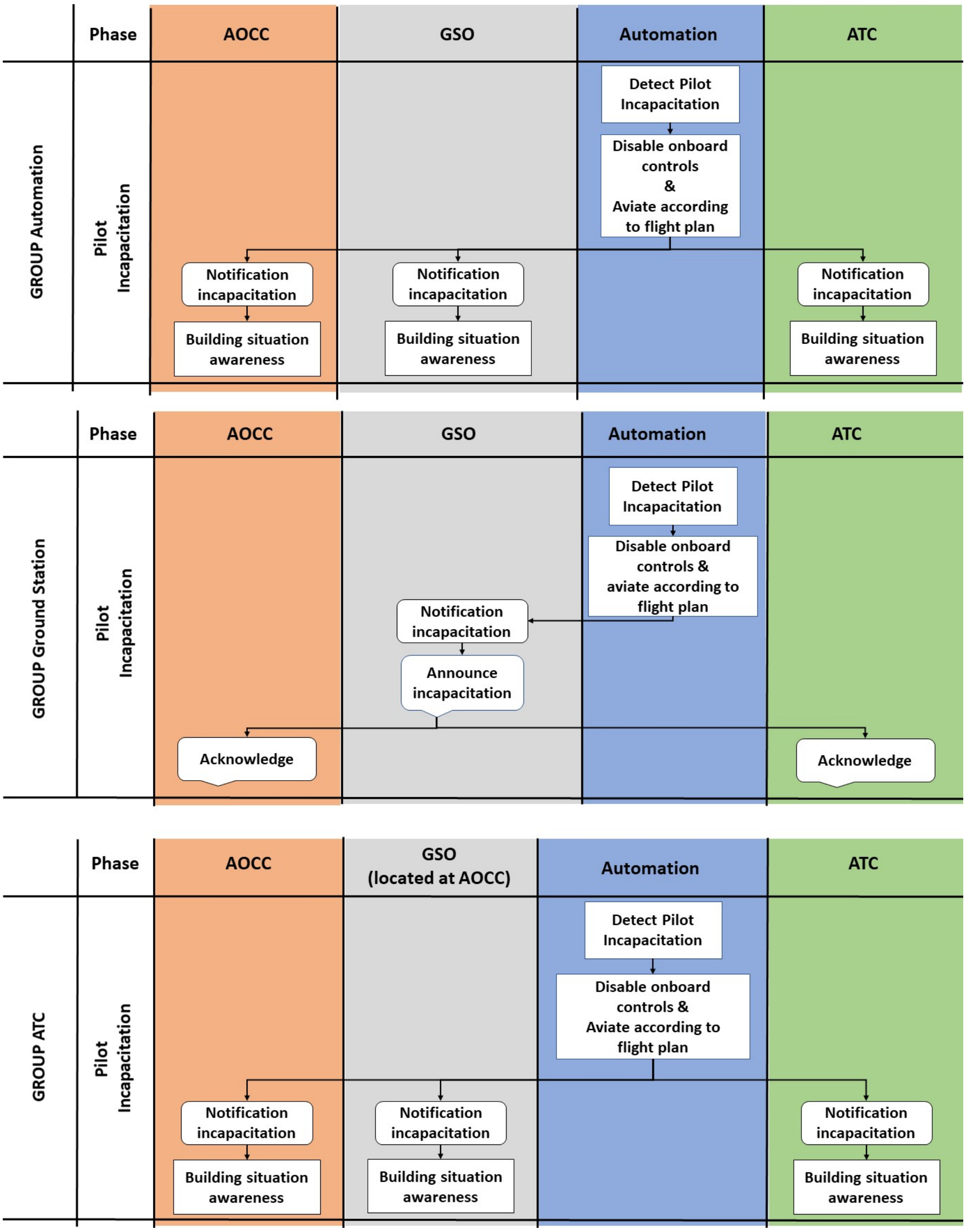


Figure 11. Comparison of the pilot incapacitation phase between the three variants

Naturally, the **hand over phase** differs significantly in each variant as the responsibility of controlling the aircraft would be allocated to different actors (cf. Figure 12). As an example, Group ATC introduces an entirely new role called "dedicated ATCO" to the ATM framework. This new role is exclusively appointed to handle the incapacitated pilot´s aircraft until it safely lands, hence taking over some of the tasks assigned to the GSO in the other variants of a concept. Within the two other variants the GSO is the main human ground operator responsible for ensuring the safe landing of the aircraft, and the ATC role is mainly to clear the path for the concerned aircraft.

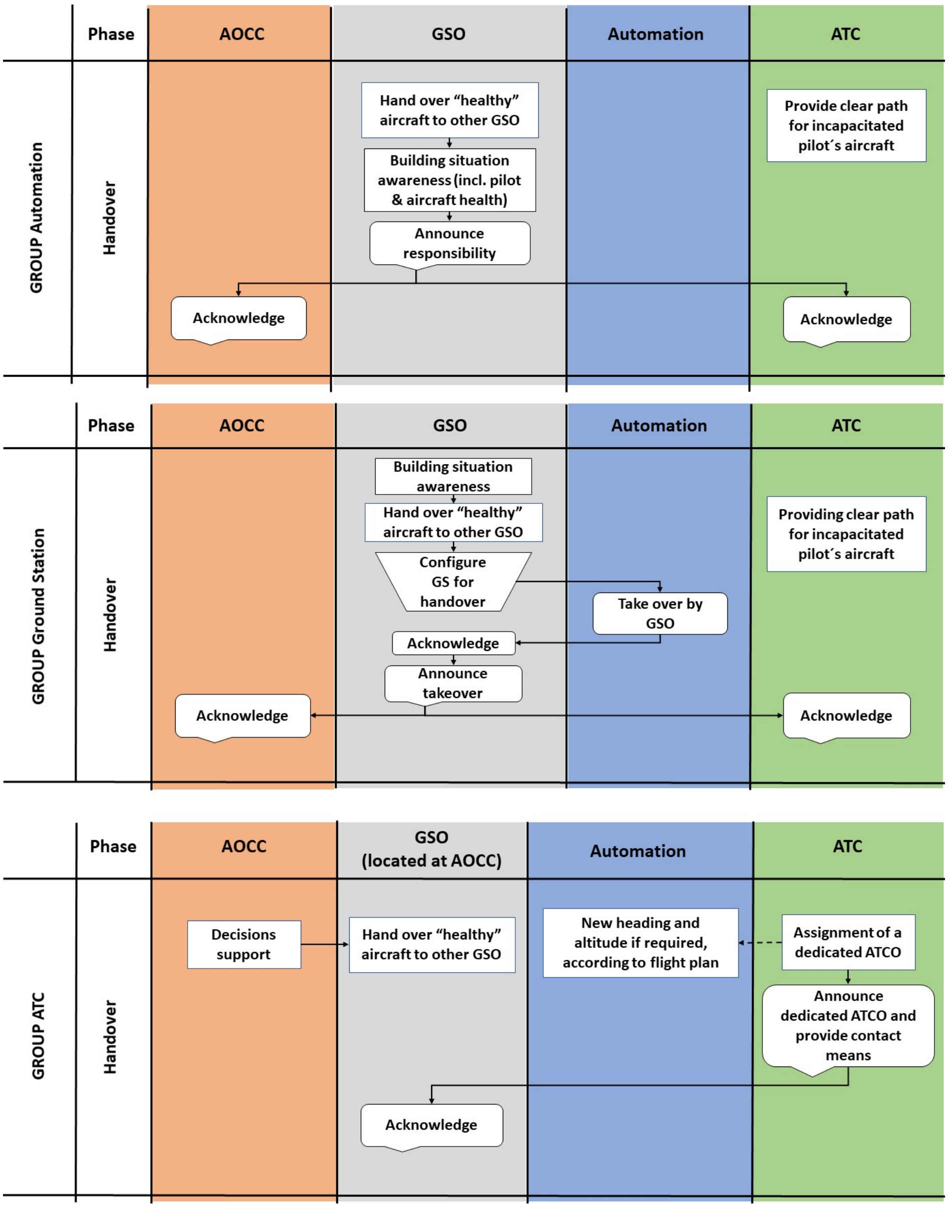


Figure 12. Comparison of the handover phase between the three variants

As illustrated in Figure 13, the **airport selection** phase has key similarities, as well as key differences between all three variants. The most significant similarity is that the GSO would always have the final decision on where to land. Obviously, in the variant where the main responsibility was defined to be given to the GS, the GSO would (most likely) decide on the alternate airport. In the variant with focus on automation, the decision where to land also had to be given to a ground operator as in current operations flight liability cannot be appointed to automation (cf. chapter 3.4). In consequence, the decision for an alternate airport is appointed to the GSO as this operator has the best situation awareness including e.g. other air traffic and will (most likely) be an airline employee (cf. chapter 3.3.1). The main reason to delegate the decision of the alternate airport to the GSO in Group ATC is to keep liability with the airline. As argued in chapter 5.3.1, the GSO, located at AOCC, will have a detailed overview of the aircraft´s situation, as well as be familiar with airline specific procedures in emergency cases and therefore be able to make the decision regarding the alternate airport.

One key difference between all three variants is the allocation of the **generation of the new trajectory to the chosen airport** (i.e. flight plan generation). For Group Automation, AOCC has a vital role: the generation of the new trajectory will be appointed to AOCC in order to take advantage of airline personnel experience with airline specific emergency procedures. Group ATC, however, involves the dedicated ATCO in this discussion with AOCC and the GSO as s/he is familiar with the airspace, knows the aircraft position and the waypoints to reach the airport. Hereby, the ATCO can provide waypoints in own sector enabling the aircraft to exit the sector, as well as coordinate with the ATCO from the other sectors. The ATCO is not expected to issue the whole flight plan until landing. Group GS considers that the GSO is generating the new trajectory to the alternate airport (e.g. consisting of a direct to command to the alternate airport) within the FMS configuration tasks as s/he would have all the relevant information to accomplish this task. In this sense, the GSO would have generated a flight plan as s/he is mainly responsible for controlling the aircraft in this concept.

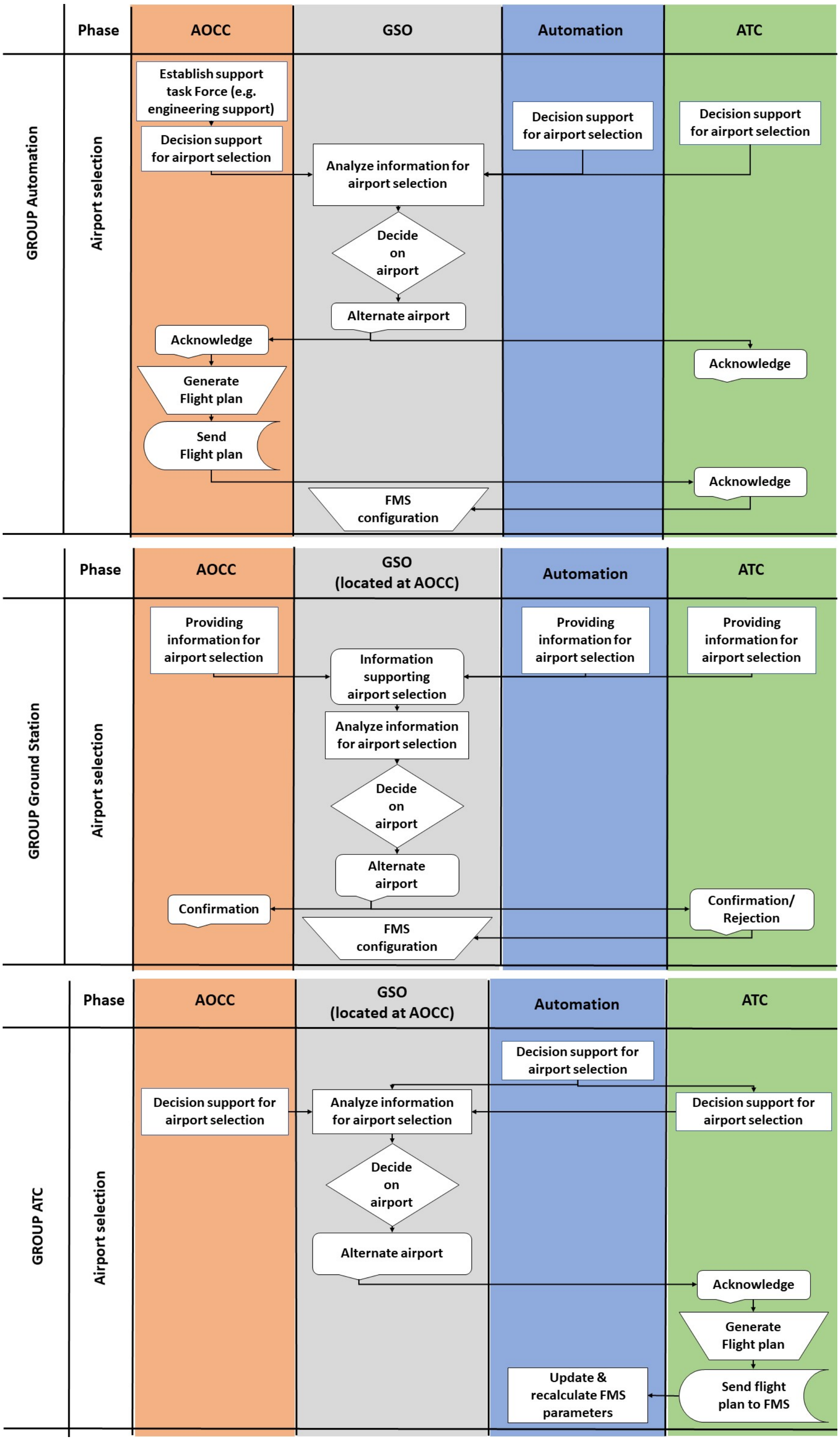


Figure 13. Comparison of the airport selection phase between the three variants

During the **emergency descent and landing** phase the onboard automation has a pivotal role in all three variants (cf. Figure 14). For Group Automation and Group ATC the automation is envisioned to land the aircraft based on the previously defined flight path and landing procedures (e.g. airline operating procedures for landing in emergency situations). For Group GS the GSO will configure the FMS based on the agreed alternate airport (e.g. outer marker waypoint) and send the final landing procedures to the onboard automation (e.g. runway conditions). ATC´s role in all variants is to clear the airspace for this concerned aircraft. Note that in Figure 10 (Group ATC) this not depicted as the ATC column represents the interaction of the dedicated ATCO after his/her announcement.

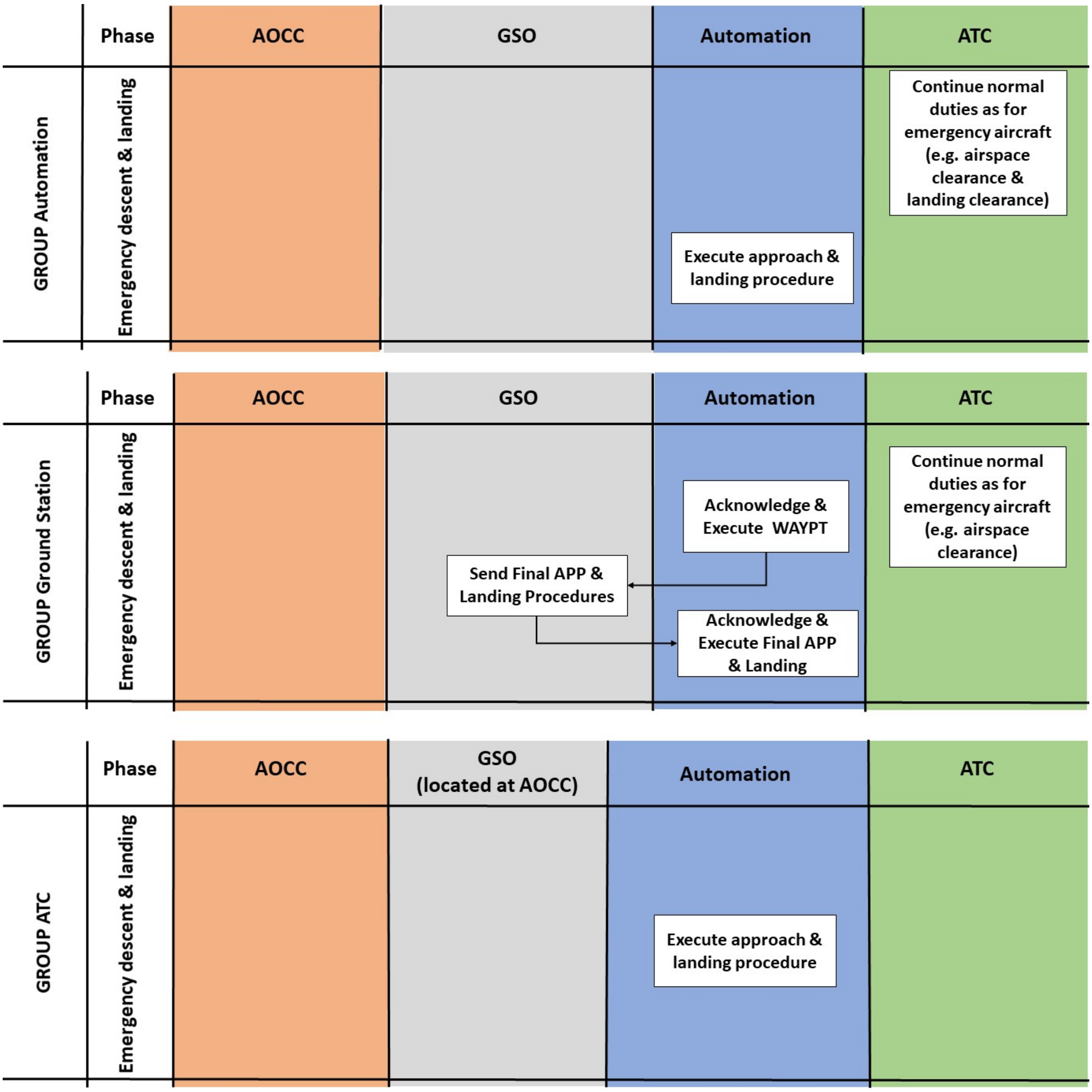


Figure 14. Comparison of the emergency descent and landing phase between the three variants

6.1.3 Location of the Ground Station

As described in chapters 3.3, 4.3 and 5.3 each concept variant envisions the most feasible and sensible **location for the GS to be at the AOCC**. First, by locating the GS in the AOCC facility, potential liability concerns would be addressed as the GSO would be an airline employee and in consequence the airline would stay liable for the aircraft, despite the fact that the onboard pilot is incapacitated. Second, the proposed location would bear the potential for specific support from other airline employees for this particular aircraft with as little as possible time delay as a close communication line would be ensured. In addition, the GSO, as an airline employee, would have access to airline and aircraft specific information (e.g. maintenance log) without requiring airline approval before obtaining this information.

6.2 Major challenges

The three variants and related discussions raise several major challenges that need to be addressed in the next steps of SAFELAND. Especially questions related to the flight authority after the incapacitation, methods for aircraft handover, as well as the means to communicate, need to be answered. Furthermore, this deliverable focused on the cruise flight phase, which is not the most critical flight phase for a pilot incapacitation to occur. Therefore, one major challenge will be to reasonably adapt the variants to the more critical flight phases, such as take-off or final approach. The workshop showed that more sophisticated automation than today will be an essential component of future single piloted aircraft. All of these issues will be briefly discussed in the following sub-chapters.

6.2.1 Flight authority after incapacitation

The question regarding who will be liable and have the final authority over the aircraft after the pilot´s incapacitation and how this liability/ authority transfer would be announced, needs to be answered in the course of the project. Groups GS and Automation concluded that the GSO would become the PIC once the incapacitation has been detected, and therefore authority and thus responsibility is transferred to them.

However, Group ATC foresees that the dedicated ATCO would be able to interact with the onboard autopilot and FMS to upload the new trajectory. The GSO would make the final decision on which alternate airport would be chosen and would keep on monitoring the aircraft system health. As such, this variant implies a shared authority of the aircraft between the dedicated ATCO and the GSO. Whether this is feasible from a legal perspective needs to be clarified. Another related problem is the potential acceptability issues from the ATCOs if they are expected to interact directly with aircraft automation. In current operations pilots are able to reject the clearances for safety or other reasons as ultimately, they are the ones responsible for the aircraft. In case of pilot incapacitation, the ATCOs might feel more comfortable if the GSO accepts or rejects the clearances before they are transmitted to the aircraft.

Finally, as concluded in chapter 3.4, it is clear that with the current applicable legislation, flight authority and liability cannot be given to automation, hence this authority will have to be transferred to human operator on ground in case of pilot incapacitation in SPO.

6.2.2 Aircraft handover

An issue that is imperative to consider within the SAFELAND concept, is the method for initiating aircraft handover from the incapacitated pilot to a new actor on ground who is responsible for the aircraft. Group GS discussed various options, such as entering a password or pressing a dedicated button, which then in turn would also initiate the "handover" message to ATC, the aircraft and possibly other actors within the AOCC besides the GSO. In any case, the method and procedures need to be standardized, safe, secure and in line with legal constraints. A careful analysis comparing the effectiveness and feasibility of different methods will need to be conducted and evaluated. This matter is further discussed in chapter 6.2.4.1.

Closely related to this is the security aspects associated with transmitting clearances to the aircraft from the ground. The secure connection between the GSO and the aircraft is implied and is already being addressed by several projects, but the approach advocated by Group ATC would also require a secure connection between the ATC Center and the aircraft. However, improving ATM systems security has already been identified as an important contributor to SESAR. As stated in the European Master Plan (SJU, 2020), the ambition is to have no significant disruptions due to cybersecurity-related incidents in 2035.

6.2.3 Incapacitation during critical flight phases

For reasons of simplicity, the initial concept development activity focused on incapacitation during cruise, which allows for ample time in reacting and preparing all the actors to deal with the situation. However, the most critical phases for pilot incapacitation are the ones requiring timely action within a possibly congested airspace and close to terrain, i.e. particularly the departure and approach phases. In a second phase, the SAFELAND concept needs to be evaluated with regard to their applicability to the departure and approach phases and will possibly need to be modified accordingly. A preliminary operational concept is discussed in chapter 6.2.4.2.

6.2.4 Automation

The focus of D1.2 was on the description of different variants of the initial version of the SAFELAND concept, with different implementation options considering different actors: aircraft, air traffic controller, ground station operator and Airline Operational Control Centre. The three variants described in the previous chapters assume that new systems are in place to support them, in addition to those already established (e.g. TCAS). Below we will summarize the needs and requirements that these systems are expected to meet.

6.2.4.1 Aircraft Automation

Throughout the deliverable the term "automation" was mostly applied to designated onboard automation. This term was used very broadly and intentionally not developed in-depth. Currently, there are already projects within the Clean Sky 2 programme working on solutions for SPO focusing on aspects related to the air side perspective: all-weather operation, high precision navigation, emergency mode of operation, continuous system monitoring, among other topics. In addition, it is out of scope for SAFELAND to develop the required systems from the aircraft perspective.

Nevertheless, one of the project's objectives is to evaluate the SAFELAND concept and procedures considering different levels of onboard automation. These will be based at least partly on previous research conducted by the partners in other projects. In this chapter we will describe how two of these systems could work.

One new system mentioned by the three groups that would need to be implemented is the **onboard pilot health monitoring system or Crew Monitoring System (CMS).** As developed by ACROSS (ACROSS, 2014b), the objective of the CMS is to track crew behaviour in order to identify and prevent peak workload situations and support reduced crew operations in specific operational conditions. This requires the development of a new integrated set of crew monitoring technologies addressing at least the following situations: Signs of crew incapacitation (strokes, hypoxia, etc.); Sleepiness/Drowsiness and Sleeping; Distraction/Inattention to cockpit instruments, etc. Such a system, composed of physiological and behavioural sensors, would be non-intrusive and is expected to require little to no associated crew inputs. As an example, the head tracking technology mounted within the cockpit could support this CMS. Other projects (e.g. Clean Sky 2 REPS project) are investigating the use of cameras, wristbands and seat pressure sensors.

Another required system is one that when engaged, would be capable of **ensuring the continued safe flight and landing of the aircraft without any further flight crew intervention**. Inputs to this system would be airplane status information (both aircraft health and flight information), commands from Ground Station, Air Traffic Control (ATC) & Airline Operations Control Centre (AOCC), crew status/monitoring, and data from aircraft automated systems (e.g. autopilot). Outputs from the system would be commands to automated systems (e.g. autopilot) and messages to the GS, ATC and AOCC.

Once this system receives from the onboard pilot health monitoring system the information that the single pilot is incapacitated, it will become partially activated and alert the pilot. Depending on the concept, it would alert one or all of the following actors: GSO, AOCC and ATCO. It would then be capable of performing partial tasks (e.g. stabilization of unstable aircraft), but will not begin strategic actions until the partial activation window has elapsed. If the activation is false, the single pilot performs the sequence of deactivation, whereas if the single pilot is incapacitated, the system would become fully active.

Depending on the chosen approach to the SAFELAND concept, the new system would check and assure stable flight first and then simply alter the route in the FMS based on input from the Ground Station, the ATCO or the system itself (fully automated option)[9]. The autopilot will then instantly follow this new route following the same procedure as when the single pilot manually enters in the FMS the route to be followed.

If upon activation of this new system the aircraft is in manual flight, the system would immediately assure the stabilization of the aircraft and turn on the autopilot and the auto thrust, followed by the activation of the "managed mode", i.e. "follow the FMS", in the autopilot. However, if upon activation of the system the autopilot and auto thrust are on and in "selected mode", the current values would

[9] Security issues and risks of system hijacking from the ground will also be considered in the variants' assessments.

be kept and followed and the system would then activate the “managed modes” of the autopilot and auto thrust. Finally, if the autopilot is already in “managed mode”, it will keep on following the signals from the FMS.

Finally, from the perspective of aircraft automation it would be necessary to develop a more sophisticated system for **ground proximity and terrain avoidance.** As mentioned in chapter 3.4, there is already a system called AutoGCAS – Auto Ground Collision Avoidance System developed by Lockheed Martin for the F-16 fighter jet that uses precise navigation, aircraft performance and onboard digital terrain data to determine if a ground collision is imminent. If the system predicts an imminent collision, an autonomous avoidance maneuver is commanded at the last instance to prevent ground impact. Another system would be the more advanced Detect And Avoid (DAA) technology capable of detecting non-cooperative ground and air traffic.

In addition to these systems, it is clear that onboard automation capable of operating secondary flight controls (e.g. thrust reversers, speed brakes, flaps or landing gear) automatically, without input from the cockpit or the ground, needs to be in place.

Last of all, it could be advisable to introduce an aircraft automation to SPO that is able **to broadcast an emergency transponder code to the ground and to other air traffic** in case an emergency event (e.g. pilot incapacitation) or severe system failure (e.g. engine failure) has occurred in the aircraft.

6.2.4.2 Authority transfer in the TMA

Although out of scope of the initial analysis, Group Automation put forward an operation paradigm that would somewhat bypass the impact of an SPO incapacitation during critical flight phases, such as the approach phase.

A robust concept solution should satisfactorily address the issue of effective transition of control at very time critical flight phases like in the Terminal Manoeuvring Area (TMA; which has a very dynamic environment) or in final descent, approach or landing phases. If full autonomous flight is not foreseen (as it is the case in SAFELAND), the challenge of ensuring adequate situation awareness of the new pilot-in-command and guaranteeing his/her ability to resume the flight and lead it to a safe completion must be fully addressed.

The core of the alternative concept that Group Automation derived asks for a pre-arranged transfer of flight authority from the onboard pilot to the GSO when entering the TMA (or when starting descent). In this way, situation awareness would be kept as the transition becomes a normal procedural event and not an abnormal event. If the onboard pilot becomes incapacitated from that moment on, the issue becomes essentially a question of medical assistance for the pilot and not of ensuring the integrity and successful completion of the flight up to landing.

Another core point is the allocation of time critical functions (especially the “aviate” function) to onboard automation, i.e. the autopilot. In this way, the criticality of demanding the GSO to fly the airplane with reduced awareness (as s/he is not onboard of the aircraft) and subjectivity to communication link failures, is bypassed.

Undoubtedly, the presence of the onboard pilot greatly enhances flight safety. His/her presence should not be discarded but actively engaged in enhancing flight safety while teaming with the GSO, the new pilot-in-command. New crew resource management (CRM) should be developed in this regard, as procedures. In fact, new CRM of onboard pilot, GSO and automation should be considered.

Moreover, the development of new procedures and supporting technologies as well as the introduction of new organisational structures and roles will have to be addressed.

6.2.4.3 Other Automation

One of the goals of SAFELAND is also to identify the functionalities of possible new additional systems that could help the ground actors (e.g. air traffic controller, ground station operator) in their activity in support to the flight management. The systems described in the previous chapter are not new in the sense that the research on SPO has been underway for over a decade and the required flight deck functions and operating procedures, including coordination with the ground, are already well-known. Therefore, during the workshop and later discussions, the partners based their arguments and discussions on the systems that have already been identified by other projects.

The only exception came from Group ATC. As explained in section 1.1, the two main approaches to deal with pilot incapacitation are Replacement Through Automation and Second Pilot Displacement to the ground (Bilimoria et al., 2014; Neis et al., 2018). These two proposals assume that the role of ATC would basically remain the same, and would thus not require any new technical systems for communication or coordination between the ATCOs and the single pilot or the ground station operator. Group ATC, however, investigated the possibility that ATC could be given new tasks and responsibilities not considered by the other groups (and thus by the two most common approaches to SPO). As explained in chapter 5, the partners advanced the possibility that a **dedicated ATCO** could upload the new route via datalink directly to the aircraft. Communication between the ATCO and the aircraft could be achieved, for example, through the same data link communication pathway used by the Ground Station Operator. In addition, the flight radar, and several tools including conflict detection tools (like the Medium-Term Conflict Detection tool), and the Safety nets for Collision Avoidance/Collision Prevention, and Conformance Monitoring/Monitoring Aid could be still used by the ATCO to support situation awareness and decision-making. As today, the dedicated ATCO could communicate with the Ground Station and the other controllers through radiotelephony[10]. Note, however, that SAFELAND being an Exploratory Research project, the specific operational and technical requirements to allow the interaction between ATCO and aircraft have not yet been identified. It is expected that as the project progresses, and the final concept is further refined any potential new additional systems will be identified and described in more detail.

6.3 Outlook

With T1.2 *Concept development*, the project started the definition of the SAFELAND concept. This deliverable explored three possible approaches to handle the problem of pilot incapacitation in single pilot operations. Each of the approaches has advantages and disadvantages, limitations and they generate further questions. Before deriving conclusions on which elements should be included as well as further developed and defined in the final concept (which will be described in D1.4 *Final Concept*), two additional activities will be carried out within the scope of T1.3 and T3.2: an in-depth desk study analysing the Legal, Regulatory & Economy Constraints related to the three variants of a concept (T1.3,

[10] Radio messages exchange between the actors on the ground (e.g. Ground Station Operator, ATCO and dedicated ATCO) making use of conventional radio frequencies.

resulting in deliverable D1.3) and a preliminary evaluation workshop with external experts with different aviation related backgrounds (ATC, airline operations, etc.) as well as experts from other fields of expertise (e.g. human factors, legal, etc.) for collecting additional feedback and recommendations (T3.2 *Preliminary Evaluation*).

6.3.1 Analysis of legal, regulatory and economy constraints

The three variants of the initial concept presented in this deliverable will be subject to the assessment of its legal, regulatory and economic implications (T1.3). This task will identify advantages and disadvantages, risks and opportunities related to the three implementation options. Outcomes of the analysis will be presented in deliverable D1.3 *Legal, Regulatory and Economy constraints*.

The deliverable will first of all examine the legal, regulatory and economic framework of the SAFELAND concept. It will present the main Aviation/ATM legal and regulatory fields, concepts and sources involved, with particular regard to responsibility and liability of the different actors involved, safety and insurance, data protection and governance and labour law. Economic aspects will also be analysed.

It will then analyse the impact of the SAFELAND concept on the outlined framework, identifying a common set of constraints for the concept as well as specific constraints of each implementation option. The analysis will include an outlook of the whole operational structure as well as a focus on the single functions required, the actors involved and their interactions: it will concentrate on the regulatory requirements (e.g. pilot licences), liability shifts (e.g. PIC or AOCC duties) and data protection issues (e.g. health monitoring system data) concerning each function, as well as economic efficiency.

Finally, the deliverable will offer an evaluation of the variants on the basis of the above-mentioned constraints. It will include suggestions, recommendations, mitigation measures, and guidelines, as well as a proposal for a set of optimal implementation options, that will feed the final version of the SAFELAND concept.

6.3.2 Preliminary evaluation workshop

The three derived variants of the concept will be presented and discussed with the external experts eliciting their opinion on a variety of important issues that need to be taken into consideration for the final SAFELAND concept. Besides aspects related to sufficiently upholding situation awareness and avoiding unacceptable workload levels, one key issue will be the acceptability of the concepts by pilots and air traffic controllers as well as their legal and regulatory constraints (as mentioned in section 6.3.1). In order for the concept to be operationally feasible for airlines, its cost/benefit relation should be within acceptable margins. All of these issues including the identification of potential showstoppers of each approach will be thoroughly discussed within the scope of the one-day online workshop scheduled for January 2021.

7 References

ACROSS Project (2014a). *Concept of Operations*. ACROSS D10.1-3.

ACROSS Project (2014b). *Crew status characterization for Crew Monitoring system*. ACROSS D9.2-1.

ACROSS Project (2016a). *Final Validation Report,* Deliverable D11.4.

ACROSS Project (2016b). *Validation of Human Factors Components*. ACROSS D3.6.

Bilimoria K. D., Johnson W.W., Schutte P.C. (2014). Conceptual Framework for Single Pilot Operations, *Proc. of the Int. Conference on Human-Computer Interaction in Aerospace* (HCI-Aero 2014).

Bolstad, C. A., Riley, J. M., Jones, D. G., & Endsley, M. R. (2002, September). Using goal directed task analysis with Army brigade officer teams. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 46, No. 3, pp. 472-476). Sage CA: Los Angeles, CA: SAGE Publications.

Elix, B., & Naikar, N. (2008). *Designing safe and effective future systems new approach for modelling decisions infuture systems with Cognitive Work Analysis.* Paper presented at the 8th international symposium of the Australian Aviation Psychology Association.

Harris, D., Stanton, N.A., & Starr, A. (2015). *Spot the Difference: Operational Event Sequence Diagrams as a Formal Method for Work Allocation in the Developmentof Single Pilot Operations for Commercial Aircraft.* Ergonomics, vol 58, no. 11, pp. 1773–1791. DOI: 10.1080/00140139.2015.1044574

International Civil Aviation Organization (ICAO) (2005). *Annex 2 to the Convention on International Civil Avitation Rules of the Air.* 10th Edition, July 2005.

International Civil Aviation Organization (ICAO) (2016). ICAO Doc 4444 Procedures for Air Navigation Services - Air Traffic Management. 16th Edition. ISBN 978-92-9258-081-0

Lachter J., et al., (2014) Toward single pilots operations: The impact of the loss of non-verbal communication on the flight deck, *Proc. of HCI-Aero 2014*.

Neis S.M, Klingauf U., Schiefele J. (2018). *Classification and Review of Conceptual Frameworks for commercial Single Pilot Operations*. 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC), IEEE.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2000). *A model for types and levels of human interaction with automation.* IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30, 286–297.

SAFELAND Project (2019). Proposal number 890599.

SAFELAND Project (2020). *Model of Flight Tasks*. SAFELAND D1.1.

Save, L. , & Feuerberg, B. (2012). *Designing Human-Automation Interaction: a new level of Automation Taxonomy*. Human Factors: a view from an integrative perspective, url: https://www.hfes-europe.org/wp-content/uploads/2014/06/Save.pdf

Sheridan, T. B., & Verplank, W. (1979). *Human and Computer Control of Undersea Teleoperators.* Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, MIT

SJU. (2020). *European ATM Master Plan.* SESAR Joint Undertaking. Executive View. 2020 Edition. 176pp.

Stanton, N. A., Harris, D., & Starr, A. (2016). The future flight deck: Modelling dual, single and distributed crewing options. Applied Ergonomics, 53, 331-342

Stimpson A.J., Ryan J.C., Cummings M.L. (2016). Assessing pilot workload in single-pilot operations with advanced autonomy, Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Vol. 60. No. 1, SAGE Publications Los Angeles, CA.

Vicente, K. J. (1999). Cognitive work analysis: Toward safe, productive, and healthy computer-based work: CRC Press.

Yixiang L., et al. (2017) Commercial airline single-pilot operations: System design and pathways to certification, IEEE Aerospace and Electronic Systems Magazine, 32.7.