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SESAR 2020 PJ.14-W2-84d - Phase Overlay for ADS-B - Technical Cost Benefit Analysis (CBAT) for TRL6

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Authoring & Approval

Authors of the document

Name/Beneficiary	Date
Indra	08/09/22
Thales	08/09/22
Enaire	08/09/22

Reviewers internal to the project

Name/Beneficiary	Date
Leonardo	08/09/22
Indra	08/09/22
Thales	08/09/22
Enaire	08/09/22

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

Name/Beneficiary	Date
Indra	08/09/22
Thales	08/09/22
Enaire	08/09/22

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Date

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INTEGRATED COMMUNICATIONS, NAVIGATION AND SURVEILLANCE SYSTEMS

This Cost Benefit Analysis (CBA) is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 874478 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document provides the first version of the **Technical Cost Benefit Analysis (CBAT)** related to SESAR Solution PJ 14-W2 84d addressing "*Phase Overlay for ADS-B*".

The objective is to set up the technological benefits related to this technological solution.

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1 Executive Summary

This document provides the Technical Cost Benefit Analysis (CBAT) related to the deployment of SESAR Solution PJ.14-W2-84d that will achieve TRL6 level at the end of SESAR 2020 Wave 2. It addresses Phase Overlay for Mode S and ADS-B feature.

As PJ.14-W2-84d is a technological solution and is not linked to any other solution (operational nor technological), it will be subject to a different CBA: a qualitative analysis to study all the potential benefits this new technology could offer, and in addition, a qualitative and quantitative analysis of the estimated costs of the solution as well as the impact it may have on the ATM sector for one of the potential benefits.

Phase Overlay is an extension of current PPM waveform used, which is the current standard for ADS-B replies. With Phase Overlay, PPM messages are phase modulated (8PSK) in order to transmit 3 new bits for each PPM pulse, increasing the data transmission from 112 to 448 bits (from 56 to 204 useful bits).

This increased message capacity, would offer in the future the ***possibility*** of improvements in security and spectrum efficiency, between other that may need to be further studied. The main stakeholders impacted by this solution would be airlines (airspace users) and ANSPs using this new ADS-B communication link.

The benefit that can be analysed economically at this stage of the technology is the possibility of including security applications that could lead to infrastructure optimisation (explained in detail in the following sections). Regarding the Cost Benefit Analysis, throughout this document, it has been decided to follow the CNS infrastructure evolution opportunities [9] approach, an assessment produced by the CNS Advisory Group; and to integrate the deployment of Phase Overlay technology, thereby analysing the economic impact of the solution.

To this end, the investment (CAPEX) and operating costs (OPEX) have been considered, as well as the perceived savings from an optimised infrastructure (Minimum Operational Network concept) by introducing the new ADS-B communication link with the possibility of applications in the security field between others (these applications need to be further defined outside the scope of Solution 84d).

As previously stated, the stakeholders potentially impacted/concerned by the deployment of this SESAR solution are:

- ANSP: Air Navigation Service Providers.
- AU: Airspace Users.

These stakeholders could receive the benefits described in this document (Section 4) thanks to the technological evolution introduced by this solution. These key benefits are:

- Additional information transmission.
- Security applications.
- Spectrum efficiency.

As part of the CBA-work, the PJ.14-W2-84d Solution partners have developed a new CBAT Model (Excel-file “CBAT Model PJ.14-W2-84d V2”) to gather all the information, assumptions related to the Reference and Solution Scenarios and convert them into quantitative input in order to conduct the

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CBAT analysis. Due to the difference nature between the stakeholders (because of different assumptions and data), it has been decided to conduct a separate analysis, in order to obtain realistic and contrasted information on the impact that the assumed inputs may have on the final result of the Cost Benefit Analysis. **Using this approach, the Net Present Values calculated by the CBAT are:**

- ANSP analysis: 34,4 MEUR.
- AU analysis: 42,3 MEUR.

In relation to the payback year, if only the analysis of ANSPs is considered, the benefits start from the Start of Deployment (SOD), as the investment made compared to the reference scenario is lower in the solution scenario. Therefore, benefits are obtained in the form of avoided investment (avoided CAPEX), and from the Initial Operational Capability (IOC), in the form of avoided operating cost (avoided OPEX). However, regarding the AUs analysis, the payback year is delayed until 2032, being necessary to make a first investment and obtaining benefits from the indicated date. Taking into account both analyses, the payback year would be in 2026, and therefore the economic benefits of this solution would be reflected from the beginning.

The main uncertainties/limitations identified in this CBA are mainly linked to 2 of the assumptions made at to build the analysis:

- ANSP analysis: The added cost of ADS-B stations with Phase Overlay technology compared to the cost of ADS-B stations without Phase Overlay.
- AU analysis: The discount in service provision fees per flight due to the profit achieved in the ground segment (ANSPs analysis).

These assumptions have therefore a significant impact on the level of confidence of the CBA. Their influences on e.g. the NPV has been investigated as part of the sensitivity analysis (Section 8), as well as the impact of the discount rate on the NPV.

Although the first assumption has a large impact on the NPV of ANSPs, the main observation is that the NPV always remains positive, which is a very good indication that the stakeholders can expect a profit. Nevertheless, the discount in service provision fees per flight have a major impact on the final NPV of AUs, and at the same time are directly dependent on the ANSP analysis. That is why the airspace analysis only serves as feedback on the outputs that influence, as well as on the expected future evolution of this stakeholder.

For all these reasons, this AUs analysis should not be taken as truthful, but as an orientation exercise to get an overview of where this solution would have an economic impact.

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2 Introduction

This CBAT document is a first version reviewed and discussed with PJ19.04 and SESAR Joint Undertaking (SJU), as indicated in the template guidelines. The process of developing this document has been composed of conducting this first qualitative and quantitative study on the costs and benefits of the solution and, after discussion with SJU and PJ.19.04, making the relevant changes that are agreed by the three parties. As described in the Handbook, the CBAs for Technological Solution should be discussed between each Solution, the SJU and PJ.19-04 to agree on a relevant scope. Data used in Solution CBAs (OI-Step, Enablers, Stakeholders, dates (IOC/FOC)) need to be consistent with the data in EATMA.

2.1 Purpose of the document

This document provides the Technical Cost Benefit Analysis (CBAT) related to PJ.14-W2-84d Solution. Since PJ.14-W2-84d is a technological solution, and it is not linked to an operational solution from which derive operational benefits that could allow the development of a proper Cost Benefit Analysis, a qualitative analysis to study the potential benefits and a quantitative analysis of the estimated costs and savings of the solution will be performed throughout this CBAT document. The main source of information used is the CNS infrastructure evolution opportunities [9], an economic assessment on behalf of the CNS Advisory Group. In this document, the basis for the Ground Segment forecast in terms of surveillance at ECAC level is stated.

2.2 Scope

This document provides the CBAT related to SESAR2020 PJ.14-W2-84d Solution reaching TRL6 level at the end of SESAR 2020 Wave2. The geographical scope is the entire ECAC-region and the main stakeholders impacted by this solution would be airlines (airspace users) and ANSPs using this new ADS-B communication link.

2.3 Intended readership

For this first draft, the intended audience for this document includes:

- SJU;
- SESAR 2020 Solution 84;
- SESAR 2020 PJ19;
- Any other SJU project that may require the information included in this document for their activities.

2.4 Structure of the document

The structure of the document is composed of the following sections:

- **Section 1** provides an executive summary.

- **Section 2** introduces the purpose and scope of the document and provides a description of the intended readership and background information. It also provides a list of acronyms used in this document.
- **Section 3** describes in more detail the objectives and scope of this CBAT, to include:
    - Description of the "problem" addressed by the Phase Overlay solution and the objectives of this technical cost benefit analysis;
    - Identification of stakeholders;
    - Description of the reference and solution scenarios; and
    - Summary of assumptions made during this analysis.
- **Section 4** describes the foreseen benefits of the solution scenario.
- **Section 5** provides a cost assessment, described per user type.
- **Section 6** provides a placeholder for the Solution 84d ad-hoc CBAT model.
- **Section 7** provides a placeholder for the results of CBAT model in section six.
- **Section 8** provides a placeholder for the sensitivity and risk analyses associated with the results of the formal CBAT model.
- **Section 9** lists recommendations and next steps.
- **Section 10** lists references and applicable documents.
- **The Appendix** provides a mapping between ATM Master Plan Performance Ambition KPAs and SESAR 2020 Performance Framework KPAs, Focus Areas and KPIs.

2.5 Background

Phase Overlay is an extension of current PPM waveform used, which is the current standard for Mode S replies and ADS-B.

Phase Overlay was proposed in ICAO Technical Group in June 2008. Within SESAR programme, first feasibility studies were conducted during SESAR-1 until V1 level and the ADS-B security applications were opened as a possibility.

Standardisation study for Mode S and ADS-B started in 2016 in the frame of the Combined Surveillance Committee group, resulting in the creation of regulation drafts ED73F/DO181F and ED102B/DO260C.

During SESAR 2020 Wave 1, in the frame of PJ14-04-03 Task 06, Phase Overlay was studied reaching a TRL4 level, developing a transmitter and a receiver prototype that were validated at laboratory level. The conclusion of these activities was that the use of Phase Overlay receivers was a good candidate to increase the capacity of the ADS-B data link and they can co-exist with existing ADS-B ground stations. Anyway, there was recognised that future activities were needed to demonstrate the viability of the technology in a real operational environment. As the draft versions of the ED73F/DO181F and ED102B/DO260C standards were not contemplating any security application, the validation activities did not include any of those aspects.

In addition, during SESAR 2020 Wave 1, a High-Level Economic Appraisal was provided as an appendix to the TVALR [15] rather than a formal CBA. It defined the Reference and Solution Scenarios, the stakeholders involved, and the potential benefits of the solution. The content of this appendix -

developed by the PJ14-members and agreed with the SJU - was exclusively based on a qualitative analysis of the costs and benefits, which was acknowledged as an appropriate approach for the Technological Solutions reaching TRL4 in SESAR 2020 W1.

2.6 Glossary of terms

Term	Definition	Source of the definition
CBA	An evaluation method that provides a logical and consistent framework for assessing a particular option or options. A CBA gives an indication of the total economic welfare effects of a project by comparing all costs and benefits.	ICAO, DOC 9829 Guidance on the Balanced Approach to Aircraft Noise Management 2008, 2nd ed., p. (v)
CBAT	Specific document for technological solutions. A CBAT contains the relevant information of a Cost Benefit Analysis (CBA), considering the limitations that may appear as a technological solution.	Solution 84d
PPM	Modulation technique used for Mode S replies where a pulse transmitted in the first half of the bit position interval represents a binary ONE, whereas a pulse transmitted in the second half represents a binary ZERO.	ICAO (2004) doc. 9684 Manual of the Secondary Surveillance Radar (SSR) Systems
Phase Overlay	A means of increasing the throughput on 1090MHz frequency by overlaying 8PSK phase modulated information onto the PPM messages. Such messages contain additional information without changing the time occupancy of the frequency and remaining within the defined spectrum characteristics.	EUROCAE/RTCA ED-73F/DO-181F
Automatic Dependent Surveillance Broadcast (ADS-B)	A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link.	ICAO Doc 4444 PANS-ATM
Mode Selective (Mode S)	An enhanced mode of SSR that permits selective interrogation and reply capability. A means by which interrogator can require from an aircraft thanks to its specific address, data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link.	ICAO (2004) doc. 9684 Manual of the Secondary Surveillance Radar (SSR) Systems

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ADS-B	Automatic Dependent Surveillance-Broadcast
AID	Aircraft ID
AIREP	Aircraft Report
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
AU	Airspace Users
BA	Business Aviation
BA-R	Business Aviation Regional
BIM	Benefit and Impact Mechanism
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CBAT	Cost Benefit Analysis Technological
CNS	Communication Navigation Surveillance
ECAC	European Civil Aviation Conference
FOC	Final Operational Capability
HC	High Complexity (airport)
HVA	Horizontal-Vertical Anisotropy
ICAO	International Civil Aviation Organization
IOC	Initial Operational Capability
IRM	Interrogation/Reply Monitoring
KPA	Key Performance Area
KPI	Key Performance Indicator
LC	Low Complexity (airport)
MHz	Megahertz
MLAT	Multilateration
MON	Minimum Operational Network

MOPS	Minimum Operational Performance Specification
NPV	Net Present Value
OE	Operational Environment
OPEX	Operational Expenditures
PIREP	Pilot Report
PAR	Performance Assessment Report
PO	Phase Overlay
PPM	Pulse-Position Modulation
PSK	Phase-Shift Keying
R&D	Research & Development
RPAS	Remotely Piloted Aircraft System
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SOD	Start of Deployment
SSR	Secondary Surveillance Radar
TMA	Terminal Manoeuvring Area
TRL	Technological Readiness Level
UAS	Unmanned Aerial Vehicle
WAM	Wide Area Multilateration

Table 2: List of acronyms

3 Objectives and scope of the CBA

3.1 Problem addressed by the solution

This section tries to describe what the CBAT is about, what decision is supported by it and what problem is addressed by the Solution. This CBAT document is an analysis of the benefits and impacts that the PJ.14-W2-84d Solution could have on ATM after its deployment.

Current PPM modulation used for ADS-B permits to transmit 112 bits in one message. With this message capacity it is possible to transmit data elements as position, speed, and other information like aircraft identification. However, ADS-B technology could be exploited to include more useful data.

This Solution is being developed to increase the capacity and the information provided in ADS-B messages via Phase Overlay technology, extending the capacity of data transmission from 112 to 448 bits (from 56 to 204 useful bits), providing space to transmit new data.

As PJ.14-W2-84d is a technological solution, it is tough to calculate tangible KPI derived from operational KPA or to make a complete Cost Benefit Analysis without having any link to an operational solution. Nevertheless, and in line with the CNS infrastructure evolution opportunities [9] assessment, the use of a passive technology like ADS-B facilitates the ground infrastructure optimisation, and thus could lead to a reduction of radio frequency spectrum congestion (explained further in Section 3.5.1.2). By adding Phase Overlay technology, increasing the useful information within a single message, and using this additional data capacity to secure the message, further optimisation of the infrastructure could be achieved. Therefore, in order to conduct this Cost Benefit Analysis, the monetary benefit will come from a possible infrastructure optimisation, which in turn comes from the technological benefits of the Phase Overlay (additional information transmission, reduced spectrum congestion and the possibility of adding a security layer to the ADS-B message).

As security benefit could be considered the key to increase the confidence in ADS-B, that would lead to maximize the rationalization of the surveillance network, and therefore, to monetised benefits in a realistic way; **the main approach of this analysis is to reduce the number of Mode S radars through the implementation of encryption in ADS-B systems by introducing Phase Overlay technology[1].** Both systems have their strengths and weaknesses, but in terms of information reliability, ADS-B is still limited:

- On the one hand, the aircraft position is obtained in a cooperative method with Mode S radars, where the aircraft provides its position data, and at the same time, the radar computes this position in order to accept it as truthful.

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[1] Phase Overlay could lead to a reduction of Mode S radars, not the removal/substitution of them, maintaining a radar-based layer in the surveillance scenario. Due to the introduction of ADS-B, the multiradar coverage will be substituted by a multisensor coverage, where one layer will be provided by radar and other layer would be provided by ADS-B. The introduction of Phase Overlay technology in ADS-B systems, providing more confidence in ADS-B (with security applications), could lead to the maximum reduction in the number of radar sensors that will conform the radar layer.

- On the other hand, since the ADS-B system is a dependent surveillance mode (non-cooperative), only the position of the aircraft is received (without any other source of information). In addition, the ADS-B message is not encrypted, so any external actor could alter, or create false position of any aircraft (see section 4.1). Given both of these characteristics of ADS-B systems, there is no way to verify that the position of that aircraft is the one stated in the message.

However, due to the increase of data in the message by introducing Phase Overlay technology, it would be possible the encryption and the addition of a unique signature, to verify that the message is the one received by the aircraft (not any external agent), and that the information in the message (position), is true. Therefore, by including Phase Overlay technology in ADS-B systems, it would be possible to reduce the number of Mode S radars, resulting in an increase in the cost efficiency of the system.

To this end, the investment (CAPEX) and operating costs (OPEX) have been considered, as well as the perceived savings from an optimised infrastructure (Minimum Operational Network concept) by introducing the new ADS-B communication link with the possibility of applications in the security field between others (these applications need to be further defined outside the scope of solution 84d).

3.2 SESAR Solution description

Solution PJ.14-W2-84d is part of PJ.14 I-CNSS "Integrated CNS and Spectrum". Within PJ.14-W2-84d, the New ADS-B communication Link is being studied.

While PPM modulation currently used for Mode S replies and ADS-B permits to transmit 112 bits (56 useful bits) in one message, Phase Overlay waveform extends the message capacity to 448 bits (204 useful bits). This solution permits to introduce several important new elements as, for instance, transmission of new data (e.g., weather information as AIREP and PIREP messages, Interrogation Rate Monitor messages; more aircraft status information as the operational coordination message or the UAS/RPAS coordination message; and HVA position and velocity messages, among others). If totally and mandatory implemented, other applications may be enabled such as the reduction of 1090 MHz spectrum congestion or the encryption of the ADS-B data.

As the guidelines define, it is necessary to identify the relationships to the ATM operational or Technical Solutions to which this technological solution is enabler for. The fact is that **PJ.14-W2-84d does not have any relationship with any Operational or Technical Solution.**

However, solution enablers are CTE-S03c (receiver) and A/C-48b (transmitter). The A/C-48b enabler is defined as "Air broadcast of aircraft data (ADS-B OUT) compliant with new ED102B/DO260C standard". Its function is the Future ADS-B Transmission. Secondly, the CTE-S03c enabler is the new ADS-B station for future ADS-B applications. Its function is the reception of new ADS-B messages (with Phase Overlay technology).

SESAR Solution ID	OI Steps ref. (coming from the Integrated Roadmap)	OI Steps definition (coming from the Integrated Roadmap)	OI step coverage	Source reference
PJ.14-W2-84d	POI-0060-SUR Phase Overlay for ADS-B	Enhancement of the ADS-B Communication Link to extend an ADS-B Phase Modulation message to encrypt information about Flight	Fully	EATMA

Phase Overlay		Number and GNSS position improving data integrity while allowing transmission of new types of information (e.g. MET information). It could also be used to improve Wide Area Multilateration (WAM) and Multilateration (MLAT) applications as well as reduce number of interrogations for ACAS-X needed today to confirm ADS-B information		

Table 3: SESAR Solution PJ14-W2-84d Scope and related OI steps

OI Steps ref.	Enabler[2] ref.	Enabler definition	Enabler coverage	Applicable stakeholder	Source reference
POI-0060-SUR Phase Overlay for ADS-B	CTE-S03c	New ADS-B station for future ADS-B applications	Fully	ANSP-CIV-CNS, ANSP-MIL-CNS, ANSP-CIV-AERO, ANSP-MIL-AERO	SESAR 2020 PJ.14-W2-84d - Phase Overlay for ADS-B - Technical Cost Benefit Analysis (CBAT) for TRL6
POI-0060-SUR Phase Overlay for ADS-B	A/C-48b	Air broadcast of aircraft data (ADS-B OUT) compliant with new ED102B/DO260C standard	Fully	AU-CIV-BA-R, AU-CIV-GA, AU-CIV-SA, AU-MIL-T	SESAR 2020 PJ.14-W2-84d - Phase Overlay for ADS-B - Technical Cost Benefit Analysis (CBAT) for TRL6

Table 4: OI steps and related Enablers

3.3 Objectives of the CBA

As PJ.14-W2-84d is a technological solution, the **main objective of this document is to outline the benefits that this improvement brings to ADS-B**, and contrast them with the cost associated with each stakeholder. For this purpose, a qualitative assessment will be made of the benefits that this technological development brings to the air traffic sector; and in addition, a qualitative and quantitative cost and savings assessment in comparison with the reference scenario. The necessary assumptions to conduct these assessments will be established, and information will be provided on decision making for the deployment of the solution, together with a sensitivity and risk analysis.

[2] This includes System, Procedural, Human, Standardisation and Regulation Enablers

3.4 Stakeholders[3] identification

This section identifies the stakeholders' categories that are affected by implementing, operating and benefitting from the Solution PJ.14-W2-84d.

Stakeholder	The type of stakeholder and/or applicable sub-OE	Type of Impact	Involvement in the analysis	Quantitative results available in the current CBAT version
ANSP	This solution is addressed to all ANSPs at ECAC level, since, as ADS-B version 2 systems, Phase Overlay technology could be introduced in the standards, and its use becomes mandatory. This is further discussed in Section 3.5. This solution would be applicable in all sub-operating environments (en-route ANS as well	**Invest:** Firstly, in order to enjoy the benefits of Phase Overlay, the equipment must be replaced/upgraded (*) to decode the signal phase. **Enjoy benefits:** ANSPs would use the full benefits of the solution in the operational environment.	In this Technical Cost Benefit Analysis only one ANSP is involved (ENAIRE). They may also provide useful data for a more detailed study of the CBAT in later versions.	Range of €100,000 - €200,000. This price could increase or decrease when considering the specific circumstances of each contract (e.g. type of station, weather conditions at the station location, etc.). The cost of the Phase Overlay technology involved in an ADS-B ground station is assumed to be between 5% and 15% of the total cost of the station, considering software upgrades and card replacement. In addition, by achieving a higher infrastructure optimisation (MON concept) there will

[3] Note that the terminology used to describe AU stakeholders in the CBA differs from that associated with Enablers in the dataset. This is due to costing being provided for different types of aircraft regardless of the operations they perform.

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	as TMAs or airports, service to High Complexity ACCs, etc).			also be benefits in the form of savings.
Airport Operators	N/A	N/A	N/A	N/A
Network Manager	N/A	N/A	N/A	N/A
Scheduled Airlines (Mainline and Regional)	This stakeholder is an airspace user, which will be able to use this solution in all phases of flight, and therefore in any sub-OE.	As part of the airspace users, this stakeholder will enjoy the benefits in operations, increasing the safety of the ADS-B message, and the information transmitted (MET). This is possible by changing/upgrading (*) the on-board transmitter, having an impact on the investment costs of all airlines interested in Phase Overlay technology.	Not involved	Considering only the cost of adapting the transponder to add the Phase Overlay applications, the price would be in the range of €25,000 to €35,000. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to €65,000 to €100,000, depending on the circumstances of the replacement of each unit. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
Business Aviation	This stakeholder is an airspace user, which will be able	As part of the airspace users, this stakeholder will enjoy the benefits in operations,	Not involved	Considering only the cost of adapting the transponder to add the Phase Overlay

	to use this solution in all phases of flight, and therefore in any sub-OE.	increasing the safety of the ADS-B message, and the information transmitted (MET). This is possible by changing/upgrading (*) the on-board transmitter, having an impact on the investment costs of business aviation sector interested in Phase Overlay technology.		applications, the price would be in the range of €25,000 to €35,000. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to €65,000 to €100,000, depending on the circumstances of the replacement of each unit. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
Rotorcraft	This stakeholder is an airspace user, which will be able to use this solution in all phases of flight, and therefore in any sub-OE for IFR flights.	As part of the airspace users, this stakeholder will enjoy the benefits in operations, increasing the safety of the ADS-B message, and the information transmitted (MET). This is possible by changing/upgrading (*) the on-board transmitter, having an impact on the investment costs of the rotorcraft sector interested in Phase Overlay technology.	Not involved	Considering only the cost of adapting the transponder to add the Phase Overlay applications, the price would be in the range of €25,000 to €35,000. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to €65,000 to €100,000, depending on the circumstances of

				the replacement of each unit. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
General Aviation IFR	This stakeholder is an airspace user, which will be able to use this solution in all phases of flight, and therefore in any sub-OE.	The information received is useful for IFR flights. As part of the airspace users, this stakeholder will enjoy the benefits in operations, increasing the safety of the ADS-B message, and the information transmitted (MET) This is possible by changing/upgradin g (*) the on-board transmitter, having an impact on the investment costs of IFR flights interested in Phase Overlay technology.	Not involved	Considering only the cost of adapting the transponder to add the Phase Overlay applications, the price would be in the range of €25,000 to €35,000. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to €65,000 to €100,000, depending on the circumstances of the replacement of each unit. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
General Aviation VFR	N/A	N/A	N/A	N/A
Military – Airborne	This stakeholder is an airspace user, which	As part of the airspace users, this stakeholder will enjoy the benefits	Not involved	Considering only the cost of adapting the transponder to add the Phase

	will be able to use this solution in all phases of flight, and therefore in any sub-OE.	in operations, increasing the safety of the ADS-B message, and the information transmitted (MET). This is possible by changing/upgrading (*) the on-board transmitter, having an impact on the investment costs of all airlines interested in Phase Overlay technology.		Overlay applications, the price would be in the range of €25,000 to €35,000. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to €65,000 to €100,000, depending on the circumstances of the replacement of each unit. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
Military – Ground	This stakeholder is a service provider in the military environment, so it would only apply to this area.	Similar to ANSPs, a replacement/upgrade (*) of the ground equipment is necessary for decoding the signal phase. It would therefore impact on the investment cost of military ground stations, and would provide access to enjoy the benefits of Phase Overlay technology.	Not involved	*R*ange of €100,000 - €200,000. This price could increase or decrease when considering the specific circumstances of each contract (e.g. type of station, weather conditions at the station location, etc). The cost of the Phase Overlay technology involved in an ADS-B ground station is assumed to be between 5% and 15% of the total cost of the station, considering

				software upgrades and card replacement. In addition, by achieving a higher infrastructure optimisation (MON concept) there will also be benefits in the form of savings.
Other impacted stakeholders (ground handling, weather forecast service provider, NSA….)	Manufacturers	**Invest:** economic contribution in R&D for the development of the technology, as well as the manufacture of the equipment. **Enjoy benefits**: economic profit after the deployment of the solution and its purchase by users.	Develop the prototype: Thales is in charge of the transmitter prototype and Indra is in charge of the receiver prototype. Participate in the development of this Technical Cost Benefit Analysis. In particular, the technological benefits of the solution will be studied, comparing the Solution Scenario with the Reference Scenario. The Solution Scenario shows potential unimplemented benefits that Phase Overlay technology could enable.	Minimal associated development costs are estimated, as is the development evolution of the current ADS-B version 2.

Table 5: SESAR Solution PJ14-W2-84d CBAT Stakeholders and impacts

(*) This solution does not necessarily involve a complete change of the ADS-B systems, nor the infrastructure that supports them. In general, Phase Overlay is compatible with current systems, so the most likely scenario would be an upgrade, through a modulation/decode card replacement (ground station), or software enhancements (transponder). This upgrade would be significantly less expensive than a full replacement. Even so, a scenario with complete replacement of the systems can be considered as a worst-case for a sensitivity analysis of the solution.

3.5 CBAT Scenarios and Assumptions

This section will describe the Reference Scenario and Solution Scenario after the deployment of the solution and explain the assumptions taken to define these scenarios. However, as this is a technological solution and, as a TS-IRS has been developed instead of a SPR-INTEROP/OSED, both scenarios will be defined on basis of what has been defined previously in the project and in line with the CNS infrastructure evolution opportunities, which will be described hereafter.

3.5.1 Reference Scenario

Reference Scenario is an airspace where the ADS-B surveillance reports are transmitted using the current PPM modulation. To define the Reference Scenario, the current situation of ADS-B systems and Mode S radars will first be presented, and then it will be described the evolution of this reference scenario as proposed by the CNS Advisory Group in the CNS infrastructure evolution opportunities [9] document.

3.5.1.1 Current situation

The reference scenario is heterogeneous. Current ADS-B version 2 corresponds to the EUROCAE ED-102A/RTCA DO-260B Minimum Operational Performance Specification (MOPS) and its deployment has not yet been fully realised and is constantly evolving, for both ground and airborne equipment. Currently, according to Eurocontrol data [21], more than 1000 ADS-B ground stations have been deployed by European ANSPs over the last several years. These are part of multilateration systems (which consist of ADS-B stations), Mode S radars with ADS-B functionality, but also standalone ADS-B systems.

It is estimated, according to Eurocontrol [21], that ADS-B is currently used for operational air traffic services (ATS) by European ANSPs over more than 6 million square kilometers or ~25% of Europe's total area. Further growth of ADS-B ground operations is expected in the next years. In order to conduct a cost benefit (savings) analysis, an estimate of this growth will be made with data collected from previous years, making an approximation of the future number of surveillance systems, both ADS-B and SSR (A/C with S-Mode).

The following image shows the evolution of the deployment (yellow) and operation (green) of ADS-B stations between 2020 and 2022:

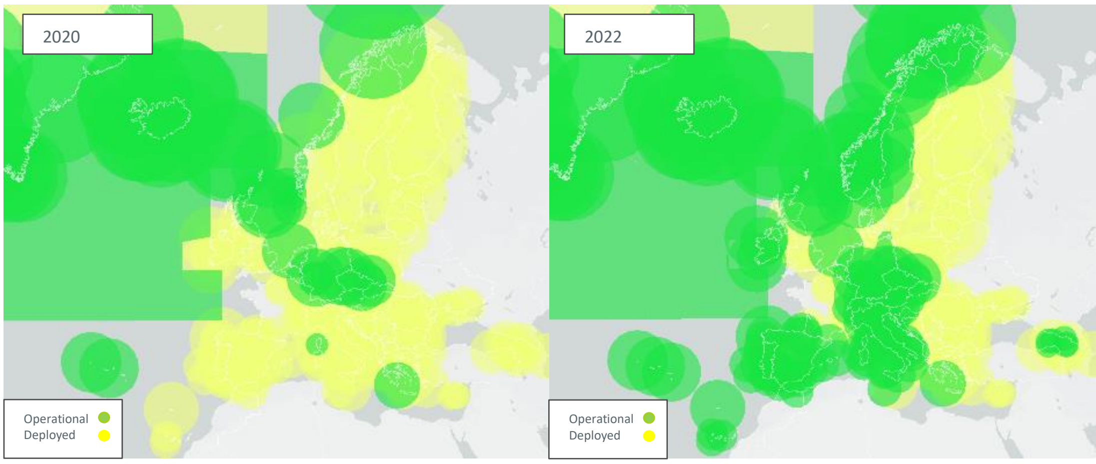

Figure 1: ADS-B coverage estimated expansion from 2020 to 2022 [21] (source: Eurocontrol)

On the other hand, there is also an increase in the number of aircraft being equipped with ADS-B transponder version 2 as required by the European Commission Regulation (EU) 1207/2011 (SPI IR) and its subsequent amendments.

The graph below shows how on-board equipment has evolved, reaching approximately 90% of the number of aircraft in Europe and 90.4% of flights operating with ADS-B version 2. Considering equipment compliant with any MOPS version, the value rises to 93%.

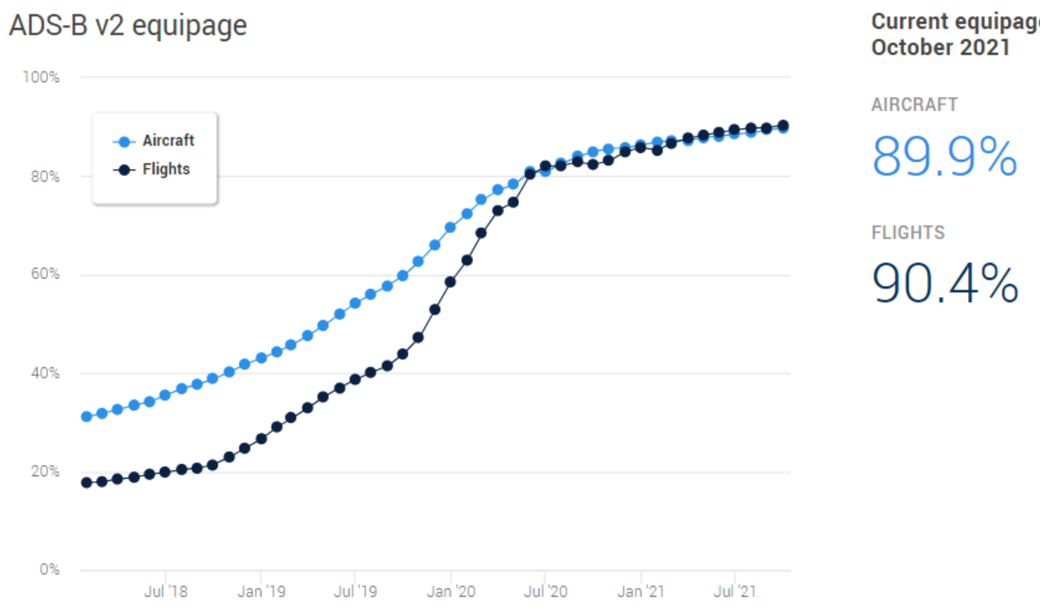

Figure 2: Aircraft and flights with ADS-B V2 equipage in October 2021 [21] (source: Eurocontrol)

These variations give an idea of what might happen in case of implementing the new version 3 transponder with Phase Overlay.

3.5.1.2 CNS infrastructure evolution opportunities approach

The CNS infrastructure evolution opportunities assessment gives a first estimate of the potential cumulative benefits to be realised through decommissioning unnecessarily redundant CNS infrastructure across the pan-European ATM network (MON concept).

The use of a passive technique, such as ADS-B, as part of the SUR target architecture will significantly reduce frequency congestion in the 1030/1090 MHz spectrum by reducing over-interrogation of airborne equipment. This improves the efficiency and sustainability of the SUR architecture, which in turn leads to operational and additional economic benefits. In the light of the above and earlier work on the subject, the SUR sensor optimisation strategy should aim at:

- Reduction in the number of PSR, SSR Mode A/C/S radars;
- Shift towards sensor types with lower cost, i.e. MLAT/ADS-B or ADS-B only; and
- Expansion of the sharing practices between the stakeholders (cross-border, civil-military, network level-local level).

The table below shows the number of facilities currently in the Surveillance network, as well as how many facilities would be retained in the future theoretical Surveillance MONs:

ECAC Area	SURVEILLANCE		
Facility (Units)	Mode A/C	Mode S	MLAT/ADS-B
Current Network	150	325	1059
Future MON	0	162	1200

Table 6: Expected facilities at ECAC level for Reference Scenario.

Therefore, in the Reference Scenario, a decreasing tendency in the number of Mode A/C and Mode S radars is expected, while the number of ADS-B sensors is forecast to increase.

This assessment does not include the analysis of airborne equipment, so its future projection will be linked to the evolution of the fleet size at ECAC level. This will be explained in the Solution Scenario.

3.5.2 Solution Scenario

Solution Scenario is an airspace (TMA, Airport and En-Route) where the ADS-B surveillance reports are transmitted either using the current PPM modulation or the new Phase Overlay modulation standard.

The installation of on-board transmitters and ground station receivers capable of using Phase Overlay as well as current ADS-B messages (new Phase Overlay systems ensure backwards compatibility with current PPM systems) would be the only change needed if this solution was deployed (also applicable to a satellite-based solution). However, Solution Scenario could be affected depending on the degree of the deployment of the solution. According to current regulations and standards, the use of Phase Overlay technology is ***optional***. Therefore, it is difficult to know the scope of the deployment, and consequently, three different scenarios are going to be defined in order to cover all possibilities.

After defining each scenario, the Solution Scenario chosen for the assessment and the reasons why it has been selected will be established.

3.5.2.1 Solution Scenario #1

The use of Phase Overlay technology is ***optional***. Therefore, PPM and Phase Overlay modulation coexist in this scenario. Although Phase Overlay technology is fully compatible with the current modulation, this would result in the benefits of the solution not being fully realised. This scenario is the most likely in the foreseeable future, as the current standards contemplate the coexistence of PPM and Phase Overlay modulation (being the latter optional). For this scenario, it will be considered that not all functions of Phase Overlay are fully exploited. Therefore, system upgrades, rather than full replacements, will be considered as the new stations would already have the new technology implemented.

3.5.2.2 Solution Scenario #2

The use of Phase Overlay technology is ***mandatory***. In this scenario, the full benefits are observed. This scenario is expected in the future, in case the Phase Overlay regulation becomes mandatory. Contrary to the previous scenario, mandatory functions of the Phase Overlay will be considered fully exploited, being necessary the complete replacement of the systems (upgrading them or installing new systems). The benefits of this solution will be explained and analysed throughout the document. As mentioned above, this solution offers an increase in message capacity, which could impact positively in applications such as security and spectrum efficiency.

3.5.2.3 Solution Scenario #3

This Solution Scenario is a combination of Scenarios 1 and 2, where Phase Overlay technology starts as ***optional*** in the standards, but becomes ***mandatory*** in the future. As previously explained, in the current situation, the full deployment of ADS-B version 2 (compliant with ED-102A/DO-260B) has not yet been completed. Airlines and ANSPs have not yet achieved a full upgrade of the technology previous to Phase Overlay (around 10% of airlines and ANSPs have not transitioned yet). In addition, the new version including Phase Overlay is optional in the current standards. Finally, taking into account the current economic framework due to the impact of COVID-19 on aviation, deployment could be delayed. Considering these three factors, it is difficult to specify when the new solution will be deployed and therefore to define a time horizon.

Hence, the concrete time-horizon of the CBAT is hardly predictable for the moment. This technology was standardized in December 2020, with the publication of the standards, opening the possibility for its deployment. However, as it is an *optional technology* in these standards, it is difficult to predict when the solution will be fully deployed and its full benefits will be realised. This full deployment will take place when the use of Phase Overlay technology becomes mandatory, however, considering the CBA support of PJ19.04, the following dates can be established:

- Start of deployment date (SOD): the start of investments for the first deployment location. Phase Overlay technology is not included in the standards as mandatory, so its use will be optional and its deployment will be reduced. It will still be implemented due to volunteers or sponsorships, or taking advantage of other equipment becoming obsolete. This phase is expected to confirm a first deployment of the Phase Overlay technology. Investment costs are spread linearly between the Start and End of Deployment dates.

- End of deployment date: the end of the investments for the final deployment location (same as FOC).

- Initial Operating Capability (IOC): the time when the first benefits (not necessary) occur following the minimum deployment necessary to provide them. Costs continue after this date as further deployment occurs at other locations.

  Although this is the definition proposed by PJ19.04, in our Solution these first benefits (compared to the reference scenario) will be reflected from the start of the deployment. Therefore, the IOC can be defined as the date when the invested systems become operational, and therefore their benefits as a system are exploited.

- Final Operating Capability (FOC): Maximum benefits from the full deployment of the Solution at applicable locations. Investment costs are considered to end here although any operating cost impacts would continue. In this phase, the solution is expected to be fully deployed throughout European territory and airspace. The start date of this phase corresponds to the date established by the standards for the transition from ADS-B version 2 to ADS-B version 3.

- End of CBA period: as specified in the PJ19.04 Common Assumptions.

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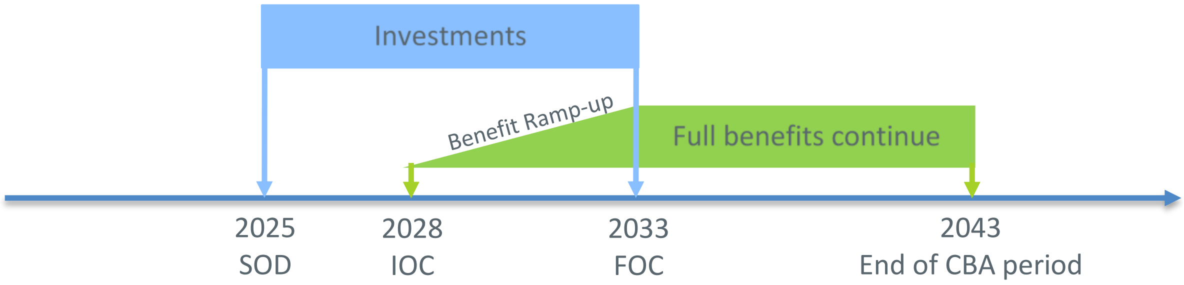

Figure 3: CBAT dates

3.5.2.4 Chosen Solution Scenario #3

After considering all the above aspects, it is decided to define a deployment in line with Solution Scenario #3. Firstly, the introduction of Phase Overlay will take place whenever previous technology that is outdated is replaced, with a linear increase in the number of installed or upgraded systems. This means that until the new Phase Overlay version is mandatory, there will only be a small number of changes in the equipage (both aircrafts and ground stations). However, as soon as version 3 becomes mandatory in ED-102 and ED-73 standards, the evolution of equipment on both ground stations and airborne side will be fully deployed. **Therefore, the scenario chosen for the assessment is Solution Scenario #3.**

In line with the Reference Scenario, in this Solution Scenario the number of Mode A/C and Mode S radars decreases in the future, while the number of ADS-B systems increases. The difference between both scenarios is that Phase Overlay technology further enhances the optimisation of the infrastructure network, due to the possibility to include applications in the field of security. In this Solution Scenario, the minimum number of Mode S radars needed decreases even more than in the Reference Scenario, and the number of ADS-B systems with Phase Overlay increases further as well.

This difference results in the operational cost of the decommissioned Mode S radars being realised in monetary benefits in the form of savings. This approach will be explained in the cost section.

The table below shows the number of facilities expected at the end of the CBAT period in the Surveillance network, in both Reference and Solution Scenarios:

ECAC Area	SURVEILLANCE		
Facility (Units)	Mode AC	Mode S	MLAT/ADS-B
Reference Scenario	0	162	1200
Solution Scenario	0	140	1400

Table 7: Expected facilities at ECAC level for Solution Scenario.

With regard to on-board equipment, the proposed Solution scenario shares the evolution of air traffic as well as fleet size in Europe with the Reference scenario. Thus, the number of transponders in both scenarios will be the same. However, in the Solution Scenario, new transponders will include Phase Overlay technology as the fleet size increases. According to an Airbus study, and based on EUROCONTROL data, there would currently be 4950 transponders at ECAC level, and it is expected to reach 8390 by the end of the CBAT period.

In addition, in this scenario, a reduction in air service charges is assumed, due to the optimisation of the ground infrastructure, in line with the CNS infrastructure evolution opportunities assessment.

This solution is intended to have a global geographic scope (in all phases of flight) on continental areas. In addition, by combining it with an ADS-B Satellite-based System, it is possible to increase its coverage to oceanic areas.

According to the Guidelines, it is necessary to identify the relationships to the ATM operational or Technical Solutions to which this technological solution is enabler for. The fact is that **PJ.14-W2-84d does not have any relationship with any Operational or Technical Solutions**. In order to define the common assumptions throughout this document, it is also necessary to determine the expected traffic evolution. Traffic evolution does not change compared to the Reference Scenario.

3.5.3 Assumptions

An "assumption" is a proposition that is taken for granted, as if it were true, in order to perform demonstrations or assessments in a specific context. Therefore, in order to perform the CBA, and considering the above assumed scenarios, the following assumptions will be taken as true:

ID	Assumptions	ID	Justifications
A.1	This new technology will be fully deployed in the frame of new standard upgrade (when Phase Overlay becomes mandatory). Therefore, Solution Scenario #3 is considered as the most realistic scenario.	**J.1**	Assumption based on experience with ADS-B version 2.
A.2	The evolution of the deployment of Phase Overlay technology will be comparable to the evolution of ADS-B version 2 when it became mandatory.	**J.2**	Assumption based on experience with ADS-B version 2.
A.3	Part of deployment will be covered by the introduction of replacement technology when old technology is being phased out.	**J.3**	Assumption based on experience with ADS-B version 2.
A.4	It is assumed that ADS-B stations are installed or have been agreed to be installed at the time of adding Phase Overlay technology. And therefore, considering the future deployment of ADS-B ground stations, the cost difference between the current version and Phase Overlay is minimal, as most of the economic investment is made in the installation of the elements common to both versions.	**J.4**	The cost breakdown is given in section 5.2, and it can be observed that the cost of implementing Phase Overlay is lower compared to the total cost of the ADS-B station.
A.4.1	It is assumed that Transponder equipment are installed or have been agreed to be installed at the time of adding Phase Overlay technology.	**J.4.1**	Assumption based on experience with ADS-B version 2.

A.5	Traffic evolution and fleet size evolution will be the same in the Solution Scenario as in the Reference Scenario.	**J.5**	The new ADS-B Phase Overlay solution does not imply changes in the evolution of air traffic.
A.6	Deployment will be equal on both the ground and airborne sides with a regulatory change compared to the current ADS-B version 2.	**J.6**	With ADS-B version 2, deployment has not been equal in both segments. In order to reduce the complexity of the analysis, it is decided to use a similar deployment within the analysis period.
A.7	When the new standards will be deployed, the Phase Overlay can be introduced by additional SW upgrade in existing systems. The major cost will be due to the standard deployment and Phase Overlay implementation cost will be negligible.	**J.7**	The cost breakdown is given in Section 5.2 and it can be observed that the cost of implementing Phase Overlay is lower compared to the total cost of the ADS-B systems.
A.8	The reference scenario is based on data on the number of existing systems and an estimation of the number of systems in the future based in the CNS infrastructure evolution opportunities assessment.	**J.8**	Sources given in Section 6.1 of the document and in Sources tabs.
A.9	Due to the new security applications offered by Phase Overlay technology, further optimisation of the infrastructure is achieved in comparison to CNS infrastructure evolution opportunities assessment. The ground segment follows a profit strategy based on the savings obtained by this optimisation.[4]	**J.9**	This assumption is based on reference documents and expert judgement and will be contrasted in the sensitivity analysis. Sources given in Section 6.1 of the document and in Sources tabs.
A.10	Following the CNS infrastructure evolution opportunities assessment scheme, as a result of the benefits obtained in the ground segment, a reduction in charges in AU analysis is obtained due to a lower cost of service provision.	**J.10**	This decrease is based on reference documents and expert judgement and will be contrasted in the sensitivity analysis. Sources given in Section 6.1 of the document and in Sources tabs.
A.11	The CBAT period and the estimated dates for the start of deployment, initial operational capability and final	**J.11**	Assumption based on information provided by SJU on CBA studies.

[4] Phase Overlay could lead to a reduction of Mode S radars, not the removal/substitution of them, maintaining a radar-based layer in the surveillance scenario. Due to the introduction of ADS-B, the multiradar coverage will be substituted by a multisensor coverage, where one layer will be provided by radar and other layer would be provided by ADS-B. The introduction of Phase Overlay technology in ADS-B systems, providing more confidence in ADS-B (with security applications), could lead to the maximum reduction in the number of radar sensors that will conform the radar layer.

	operational capability are based on the judgement of sector experts.		
A.12	It is estimated that until full operational capability is reached, the Phase Overlay system will have a linear growth from the start of deployment (SOD) to the final date of operational capability (FOC).	**J.12**	Assumption based on information provided by SJU on CBA studies.
A.13	According to the established definitions of the CBAT period dates in the document, ADS-B stations and transponder equipment with Phase Overlay become operational from IOC date.	**J.13**	Assumption based on information provided by SJU on CBA studies.
A.14	The installation costs and maintenance costs of the current systems are based on market data.	**J.14**	Estimated cost based in market price used in different studies by sector companies.
A.15	Maintenance costs are estimated at 7% of the total investment cost per year.	**J.15**	Estimated cost based on experience and expert industry judgement.
A.16	The installation and maintenance costs of ADS-B stations and transponder equipment with Phase Overlay are based on the expert judgement of solution members.	**J.16**	Assumptions and/or expert-judgements captured and recorded during specific brainstorming sessions.
A.17	The installation cost of ADS-B stations with Phase Overlay is increased by 5% to 15% of the installation cost of a current Phase Overlay station	**J.17**	Assumptions and/or expert-judgements captured and recorded during specific brainstorming sessions.
A.18	The maintenance cost of ADS-B stations with Phase Overlay is increased up to 10% of the installation cost	**J.18**	Assumptions and/or expert-judgements captured and recorded during specific brainstorming sessions.
A.19	The average of the maximum and minimum prices is established as the estimated cost	**J.19**	Due to the provision of cost ranges, an average cost is established for the analysis. The cost range will be considered during the sensitivity analysis.
A.20	It is assumed that ADS-B stations are progressively replaced by ADS-B stations with PO capacity in the solution scenario.	**J.20**	Assumptions and/or expert-judgements captured and recorded during specific brainstorming sessions.

Table 8: CBAT Assumptions (both ANSPs and AUs analysis)

4 Benefits

PJ.14-W2-84d main objective is the validation to TRL6 of the new ADS-B communication link (Phase Overlay) in order to transmit 3 new bits for each pulse using current ADS-B PPM messages as baseline [14]. This increase in useful bits could lead to the possibility of new applications in ADS-B messages, as well as new data transmitted, or the reduction of the number of messages for the same amount of data, reducing spectrum congestion.

4.1 Additional information transmission

The direct benefit of this Solution is that Phase Overlay technology allows ADS-B message to send 448 bits (204 useful bits) instead of the PPM ADS-B 112 bits (56 useful bits).

This new extended data could be used to provide new types of information or complement the information sent by current ADS-B PPM messages. From that point on, it is possible to set up some benefits that this technology could bring to surveillance performance, presented hereunder. This new information can help controllers to have more detailed information about the aircraft and its status, as well as weather and turbulence data or data related to trajectory prediction (turn angles, final state altitude, or other examples). Still, this is a simple brainstorming of possible new information, but it should be studied and detailed in further studies.

4.2 Security applications

Secure ADS-B message issue was opened as a possibility in SESAR 1, and it has worked on since then. In SESAR 2020 Wave-1, as security was not contemplated in the draft standards (ED73F/DO181F and ED102B/DO260C), this issue was not studied.

During this SESAR 2020 Wave-2, the PJ.14-W2-84d objective is to verify the new Phase Overlay modulation according to the standards published in December 2020, by checking the compliance with the requirements contained in the regulation, and providing feedback to the standardisation groups. The extended data available thanks to Phase Overlay offers the possibility of a secure ADS-B, along with encryption. Nevertheless, this solution is not going to conduct any security validation as there is no standard to apply, although PJ.14-W2-84d's recommendation is that this could be a future benefit to be studied.

Security in ADS-B messages is an important topic, and the number of threats is increasing. According to a 2019 study, "Russia frequently spoofs GPS data to mask military activity in Syria, Crimea, and elsewhere. Over 7900 ships have experienced GPS outages connected with Russian GPS spoofing activity since 2016" [24]. Considering the current war scenario in Ukraine, and the evolution of technology that has made easier and cheaper the possibility to develop spoofing devices, encryption will be even more necessary or at least advisable in the near future.

ADS-B security has been studied within SESAR programme due to the various threats the information is exposed to. In order to secure the information contained in these messages, it is necessary to protect them when possible (and when standards allow it). This topic has been discussed and established as an objective in SESAR2020 PJ.14-04-03 Task 05, being continued in Wave-2 in SESAR2020 Technological Solution PJ.14-W2-84c "Secured Surveillance Systems (Single and Composite Systems)", in order to include security appendix in future normative documents. In PJ.14-

W2-84c, several ways to threaten ADS-B service were gathered, with special attention to section 4.1.2 in its TS-IRS [13] ("*Threats at ADS-B content level*").

Within SESAR1, these threats in ADS-B PPM messages were identified as the most common ones:

- **Spoofing:** anyone can generate synthetic ADS-B tracks and duplicate real ADS-B messages (with bias). Therefore, spoofing can lead to a distortion of the real airspace situation, influencing the overall safety of aircraft. The spoofing of ADS-B tracks could result in serious accidents.
- **Eavesdropping:** anyone can track aircraft with ADS-B messages. Data in the network should only be available to authorized entities. Any activity that leads to the leak of the information to unauthorized or malicious users are against confidentiality. This is a direct threat to ANSPs, as they lose ownership of the tracking data, and it becomes open for public use. There are numerous services that take advantage of this feature of ADS-B to provide aircraft tracking. Therefore, depending on the actor involved, eavesdropping can also be considered as a benefit.

The following characteristics of the ADS-B message should be considered with the purpose of avoiding and repelling these threats:

- **ADS-B PPM message reception:** ADS-B position is transmitted spontaneously in real time without any delay. As it is not possible to induce any delay for ADS-B message transmission, there is no solution.
- **ADS-B PPM data information fields:** position, speed, barometric altitude, among others, are transmitted spontaneously in real time, without any encryption or protection. For safety and interoperability with the current standard, Phase Overlay cannot encrypt these data.
- **ADS-B aircraft authentication:** with PPM messages, aircraft ID is transmitted spontaneously in real time, without any encryption or protection. This information is needed for Flight Plan Correlation.

The possible solutions to the two main threats are shown in the following table:

Threat	ADS-B PPM message reception	ADS-B PPM data information fields	ADS-B aircraft authentication	Synthesis
Spoofing	No solution	Signature which permits the sender authentication	Signature which permits the sender authentication	Permit to guarantee authenticity of the sender. Fully interoperable with current ADS-B
Eavesdropping	No solution	No solution	No AID transmitted	Current aircraft position is public, but the identity is private. Fully interoperable with current ADS-B

Table 9: ADS-B PPM Messages Threats and Solutions

In a current PPM ADS-B message, there is no place to add a signature. Phase Overlay solution increases message capacity, which can be used to encrypt sensitive information as well as to add a signature to identify the sender.

Secure ADS-B transmission will improve data integrity and it is a good candidate for ADS-B ground station (WAM and MLAT) applications. As explained above, in a current PPM ADS-B message, there is no spare to add signature, but Phase Overlay technique permits to add 3 additional fields that can be used for signature. It could be also useful for ACAS-X in order to reduce the use of UF0/UF16 interrogations necessary today to confirm ADS-B information.

4.3 Spectrum efficiency

Nowadays, 1090 MHz radio frequency is a critical aviation resource shared by several aeronautical systems (ADS-B, WAM, ACAS, Mode S…). An excessive high-level use of the 1090 MHz frequency can result in detection losses/false detections of aircraft surveillance. It is essential to keep the usage of 1090 MHz frequency at an acceptable level in order to maintain the safety and performance of surveillance systems and to avoid the need to deploy a new link. PJ.14-W2-84d Phase Overlay could allow the reduction of spectrum congestion by compacting more information into a single ADS-B message. Phase Overlay adds 3 new messages, 112 bits each (204 effective bits due to preambles and headers needed for synchronization), allowing Phase Overlay to transmit more information than the current standard.

This benefit will not be immediately applicable after the deployment of the solution since Phase Overlay technology will be optional and will coexist with PPM standard in order to maintain interoperability for the years to come. Because of this, there will not be a reduction of signals transmitted immediately. Only in a feasible future where Phase Overlay is established as the standard, this would lead to a reduction in the number of messages (sending the same information in less time), and therefore to a decongestion of the radio frequency spectrum of 1090 MHz. This benefit can be monitored and studied thanks to another new feature of Phase Overlay technology, the Interrogation/Reply Monitoring (IRM). This data reports transponder interrogation and reply rate activity. It provides a more comprehensive monitoring and study of the radio frequency spectrum, which enables optimised spectrum management.

4.4 Monetary benefits

These technological benefits could lead to a monetary benefit in the form of savings, which are supported by an optimal rationalisation of infrastructure in the ground segment and the MON concept. This optimal rationalisation brings a decrease in the investment and maintenance costs of Mode-S radars in the Solution Scenario compared to the Reference Scenario, thus obtaining a positive NPV for the ANSPs. In turn, these savings could lead to a decrease in service fees, from which the AUs could benefit.

4.4.1 ANSPs monetary benefits

Therefore, a monetary benefit for ANSP stakeholder could be obtained by the following approach:

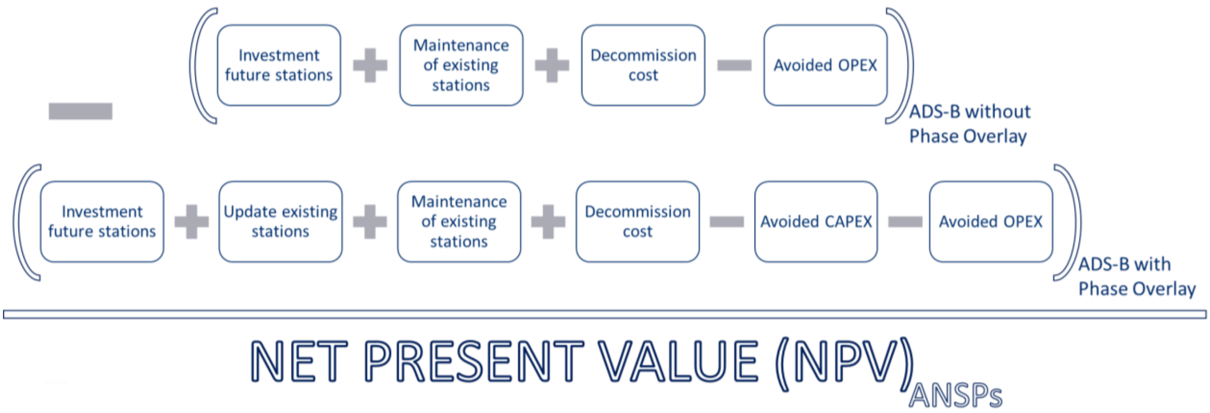

Figure 4: Net Present Value for ANSPs

Where each concept can be defined as:

Concept	Definition	Value per unit
Investment future stations	Investments of future ADS-B stations without Phase Overlay.	150.000 EUR
	Investments of future ADS-B stations with Phase Overlay.	165.000 EUR
Update existing stations	Investments of updating ADS-B stations with Phase Overlay technology.	15.000 EUR
Maintenance of existing stations	Maintenance costs for ADS-B stations without Phase Overlay.	10.500 EUR
	Maintenance costs for ADS-B stations with Phase Overlay.	16.500 EUR
Decommission cost	Decommissioning costs of Mode-S radars are treated as a reduction of savings.	323.000 EUR
Avoided CAPEX	Investments of Mode-S radars that would not be necessary any more as a result of implementing an optimisation strategy.	1.900.000 EUR
Avoided OPEX	The operating costs of decommissioned Mode-S radars would no longer be incurred.	133.000 EUR
Net Present Value	The net of the concepts above	-

Table 10: Definitions for ANSPs NPV concepts

All these costs and savings are defined on a per unit basis, therefore, to obtain a total benefit, the projection of the number of systems in both the Reference and Solution Scenarios, shown in the table below, must be considered. The complete information of these future projections, as well as the values of the associated costs and savings of the Phase Overlay solution, is available in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2") in Section 6.

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Phase Overlay Growth Factor (linear)	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

		Number of existing stations per year																			
		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Reference Scenario	ADS-B / MLAT	1119	1127	1135	1143	1151	1160	1168	1176	1184	1192	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Mode S	325	309	292	276	260	244	227	211	195	178	162	162	162	162	162	162	162	162	162	162

		Number of existing stations																			
		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Solution Scenario	ADS-B (total)	1119	1132	1145	1158	1171	1185	1198	1211	1224	1237	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
	ADS-B PO Updated	124	124	124	124	124	124	124	124	124	124	0	0	0	0	0	0	0	0	0	0
	ADS-B PO New In each year	1	3	4	5	7	8	9	10	12	13	0	0	0	0	0	0	0	0	0	0
	Mode S	325	307	288	270	251	233	214	196	177	159	140	140	140	140	140	140	140	140	140	140

Table 11: Data used in ANSP scenario computation

4.4.2 AUs monetary benefits

As in the previous section, the monetary benefit for AU stakeholder could be obtained by the following approach:

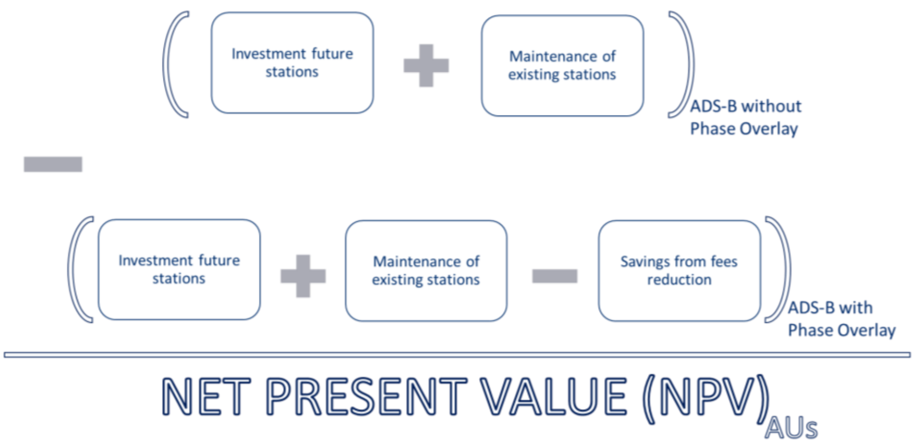

Figure 5: Net Present Value for AUs

Where each concept can be defined as:

Concept	Definition	Value per unit
Investment future stations	Investments of future ADS-B transponders without Phase Overlay.	50.000 EUR
	Investments of future ADS-B transponders with Phase Overlay.	82.500 EUR
Maintenance of existing stations	Maintenance costs for ADS-B transponders without Phase Overlay.	3.500 EUR
	Maintenance costs for ADS-B transponders with Phase Overlay.	5.775 EUR
Savings from fees reduction	Decrease in the price of fees resulting from an optimisation of the ground infrastructure of the ANSPs.	1 EUR/flight
Net Present Value	The net of the concepts above	-

Table 12: Definitions for AUs NPV concepts

As in the previous section, all these costs and savings are defined on a per unit basis, therefore, to obtain a total benefit, the projection of the number of systems in both the Reference and Solution Scenarios, shown in the table below, must be considered. The complete information of these future projections, as well as the values of the associated costs and savings of the Phase Overlay solution, as well as the evolution of traffic in the ECAC region, is available in the CBA Model (Excel file “CBAT Model PJ14-W2-84d V2”) in Section 6.

		Number of existing stations per year																			
		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Reference Scenario	TXP ADS-B v2	4950	5131	5312	5493	5674	5855	6036	6217	6398	6579	6761	6942	7123	7304	7485	7666	7847	8028	8209	8390

			Number of new stations per year																		
		2024*	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Solution Scenario	TXP ADS-B v3	0	20	40	60	80	101	121	141	161	181	181	181	181	181	181	181	181	181	181	181
	TXP ADS-B v2	4950	161	141	121	101	80	60	40	20	0	0	0	0	0	0	0	0	0	0	0

* Number of existing stations in 2024

Table 13: Data used in AU scenario computation

4.5 Benefits from other Solutions

According to Section 3.5.2, PJ.14-W2-84d does not have any relationship with any Operational or Technical Solution. Therefore, **it does not include benefits that come from the deployment of other Solutions.**

Performance Framework KPA[5]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year N	Year N+x	Year N+y
Cost Efficiency	ANS Cost efficiency	**CEF2** Flights per ATCO-Hour on duty	Nb	ATCO employment Cost change	€/year	N/A	N/A	N/A
				Support Staff Employment Cost Change	€/year	N/A	N/A	N/A
				Non-staff Operating Costs Change	€/year	N/A	N/A	N/A
		CEF3 Technology cost per flight	EUR / flight	G2G ANS cost changes related to technology and equipment	€/year	**Net Present Values:** ANSP analysis: 34,4 MEUR. AU analysis: 42,3 MEUR.	See Charts NPV in Section 7.	See Charts NPV in Section 7.

[5] For information, the mapping to the Performance Ambition KPAs (used in the ATM Master Plan) is available in the Appendix.

Performance Framework KPA[5]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year N	Year N+x	Year N+y
	Airspace User Cost efficiency	**AUC3** Direct operating costs for an airspace user	EUR / flight	Impact on direct costs related to the aeroplane and passengers. Examples: fuel, staff expenses, passenger service costs, maintenance and repairs, navigation charges, strategic delay, landing fees, catering	€/year	N/A	N/A	N/A
		AUC4 Indirect operating costs for an airspace user	EUR / flight	Impact on operating costs that don't relate to a specific flight. Examples: parking charges, crew and cabin salary, handling prices at Base Stations	€/year	N/A	N/A	N/A
		AUC5 Overhead costs for an airspace user	EUR / flight	Impact on overhead costs. Examples: dispatchers, training, IT infrastructure, sales.	€/year	N/A	N/A	N/A
Capacity	Airspace capacity	**CAP1** TMA throughput, in challenging airspace, per unit time	% and # movements	Tactical delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
			% and # movements	Strategic delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
		CAP2 En-route throughput, in challenging airspace, per unit time	% and # movements	Tactical delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
			% and # movements	Strategic delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A

Performance Framework KPA[5]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year N	Year N+x	Year N+y
	Airport capacity	**CAP3** Peak Runway Throughput (Mixed mode)	% and # movements	Value of additional flights	€/year	N/A	N/A	N/A
	Resilience	**RES4a** Minutes of delays	Minutes	Tactical delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
		RES4b Cancellations	% and # movements	Cost of cancellations	€/year	N/A	N/A	N/A
		Diversions	% and # movements	Cost of diversions	€/year	N/A	N/A	N/A
Predictability and punctuality	Predictability	**PRD1** Variance of Difference in actual & Flight Plan or RBT durations	Minutes^2	Strategic delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
	Punctuality	**PUN1** % Departures < +/- 3 mins vs. schedule due to ATM causes	% (and # movements)	Tactical delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
Flexibility	ATM System & Airport ability to respond to changes in planned flights and mission	**FLX1** Average delay for scheduled civil/military flights with change request and non-scheduled / late flight plan request	Minutes	Tactical delay cost (avoided-; additional +)	€/year	N/A	N/A	N/A
						N/A	N/A	N/A

Performance Framework KPA[5]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year N	Year N+x	Year N+y
Environment	Time Efficiency	**FEFF3** Reduction in average flight duration	% and minutes	Strategic delay: airborne: direct cost to an airline excl. Fuel (avoided-; additional +)	€/year	N/A	N/A	N/A
	Fuel Efficiency	**FEFF1** Average fuel burn per flight	Kg fuel per movement	Fuel Costs	€/year	N/A	N/A	N/A
	Fuel Efficiency	**FEFF2** CO2 Emissions	Kg CO2 per movement	CO2 Costs	€/year	N/A	N/A	N/A
Civil-Military Cooperation & Coordination	Civil-Military Cooperation & Coordination	**CMC2.1a** Fuel saving (for GAT operations)	Kg fuel per movement	Fuel Costs	€/year	N/A	N/A	N/A
		CMC2.1b Distance saving (for GAT operations)	NM per movement	Time Costs	€/year	N/A	N/A	N/A

Table 14: Results of the benefits monetisation per KPA

4.6 Impacted KPA for Solution PJ14-W2-84d after PJ19.04 assessment

PJ19.04 concluded after its assessment that Solution PJ14-W2-84d has an Indirect Safety Impact (ISI), and an impact on the KPI Cost Efficiency, specifically in the CEF3 KPI (technology cost per flight), which will be analysed in the cost assessment section.

4.6.1 Safety KPA

PJ.14-W2-84d does not have a direct safety impact, but an Indirect Safety Impact. When solutions bring changes in current technology, it is necessary to justify that this new technology reaches an adequate level of safety, as the previous one.

Phase Overlay does not interfere with technology used nowadays (PPM ADS-B), keeping interoperability between standards (ED-102A/DO-260B – ED-102B/DO-260C). As it is a technological and not an operational solution, PJ.14-W2-84d does not imply any change in operator procedures, nor any change in human performance. Therefore, no safety assessment is required.

Solution PJ.14-W2-84d has a global objective (OBJ-PJ.14-W2-84d-TRL6-TVALP-001) which is the verification use of Phase Overlay for the transmission and reception of 1090MHz ADS-B signals. This is defined in TVALP Part I [18]. Within this global objective is included the task "to verify the interoperability", ensuring the non-regression of the 'service' with respect to the current way of transmitting the message. It is demonstrated that Phase Overlay layer is not interfering with the current content of the PPM message and the performance/quality of the service in any way.

4.6.2 CEF3 KPI

The Performance Framework [20] defines CEF3 as "Technology cost per flight". This can be linked to investment costs (a stakeholder needs to buy a new component to deploy the solution) and/or to operating costs (the running costs of the new component). A solution needs to identify if both components of the costs are applicable.

Regarding operating costs, as it is a technological solution, and it is not linked to an operational solution from which derive operational benefits, there would be no difference with the Reference Scenario costs. However, to be able to conduct a complete CBA, an estimate will be made for the maintenance costs that the solution will imply in the case of deployment.

On the other hand, investment costs are applicable to the CEF3 KPI since it is necessary to change the receiver and transmitter systems. However, as currently only prototypes exist, and defining a market price is part of the commercial strategy of the companies involved in the solution; it is difficult to estimate this investment costs (transmitter and receiver market prices). However, a range of investment costs is provided in next quantitative cost assessment section.

In addition to these difficulties, there is also the challenging task of obtaining a specific number of the air fleet that will implement Phase Overlay technology in their on-board equipment. It is also a tough task to know if ANSPs will opt for a replacement strategy for their receivers. Considering these two aspects, the deployment of the solution is undecided, and therefore the cost implications for both airlines and ANSPs are difficult to account for at this stage. At the same time, it can be considered the deployment of Phase Overlay technology in satellite-based applications. Companies such as Aireon

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invest in surveillance functions such as ADS-B, which are implemented in the space segment. Due to the complexity of the system, and the fact that satellite systems cannot be significantly modified once in orbit, it is not known when Phase Overlay technology could be implemented for satellite-based applications. Before the launch of the constellation, a roadmap should define if this technology will be integrated into the payload. Therefore, it is not yet known whether Phase Overlay technology will be used in future constellations, making it difficult to study the costs that could be involved.

After several discussions between PJ.14-W2-84d members, and with PJ19.04 Cost Efficiency champions, a qualitative study has been chosen, as well as a quantitative study with a rough estimate of the prices of this technology for the time being. The quantitative study will be subject to the restrictions explained in previous sections, being dependent on strong assumptions. These analyses will be further elaborated in the following section.

5 Cost assessment

This section describes and analyses all the costs associated with the implementation of the Solution under analysis, based on the CBA Scenarios illustrated in Section 3.5. Before a quantitative rough estimation of the costs, a first qualitative assessment is shown hereunder, explaining the main blockages in the cost calculation.

5.1 Qualitative cost assessment

As explained above, after several discussions between PJ14-W2-84d members, and with PJ19.04 Cost Efficiency Champions, it was established that a first qualitatively explanation of the associated costs would be provided.

To this end, it was decided to coordinate with the PAGAR campaign, and to identify the different costs and separate them into categories, indicating whether they are high, medium, or low cost, compared to the overall cost. The different categories and their impact on the cost of the solution in a qualitative way are as follows:

- **Development cost** (**High**): this cost includes the research and development of the prototypes, that is, all the necessary activities and actions to create an operative system. However, no stakeholder enjoying the benefits of the solution will be involved in these costs.

- **Investment cost** (**High**): The investment costs include both the price of the receiver and the price of the transmitter. Compared to the reference scenario (the current ADS-B systems) this price would be a percentage higher due to the increase in performance. As explained in Section 3.4, the investment cost depends on the strategy of the different stakeholders. In case only the systems upgrade is necessary, the cost would be significantly lower than if they have to be completely replaced.

  The cost of the receiver is incurred by the ANSPs, which would have to replace/upgrade their systems at the ground stations. On the other hand, the airlines would invest in the transmitter by changing/upgrading their on-board equipment. This change or update depends on the compatibility between Phase Overlay and the transponder used.

- **Deployment cost** (**Medium**): As mentioned above, the deployment of the solution would involve a replacement/upgrade of the on-board equipment by the airlines as well as the ANSPs ground stations (including infrastructure costs). Therefore, installation of the equipment is necessary and would incur an additional cost compared to the reference scenario. Like the previous one, this cost also depends on the stakeholder situation. If ground stations and aircraft are provided with the current systems (described in standards), which are compatible with Phase Overlay, this cost would be significantly reduced.

- **Maintenance cost** (**Medium**): The incorporation of new upgrades in the ADS-B system could incur additional costs.

- **Service provision cost** (**Low**): Compared to the reference scenario, the associated cost of service provision has no significant cost increase. However, the incorporation of new upgrades in the ADS-B system could incur additional costs.

KPIs / PIs	Unit	Calculation	Mandatory	Benefit in SESAR 1 or SESAR 2020 Wave 1 (if applicable)	Absolute expected performance benefit in SESAR 2020 Wave 2	% expected performance benefit in SESAR 2020 Wave 2
CEF2[6] Flights per ATCO-Hour on duty	No	Count of Flights handled divided by the number of ATCO-Hours applied by ATCOs on duty.	No	*N/A*	*N/A*	*N/A*
CEF3 Technology cost per flight	EUR / flight	G2G ANS cost changes related to technology and equipment.	YES	*N/A*	*Not known yet*	*2*

Table 15: Cost Efficiency KPIs

Also, in line with the PAGAR campaign, a diagram (BIM) is shown below to clarify the impacted areas of the solution and their relationship to the CEF3 KPI, as explained in Section 4.6.2. A Benefit and Impact Mechanism (BIM) is a cause-effect description of the impacts of the solution proposed by the project. It also describes and identifies all relevant impacts, whether positive or negative, that the project solution is expected/ shown to provide.

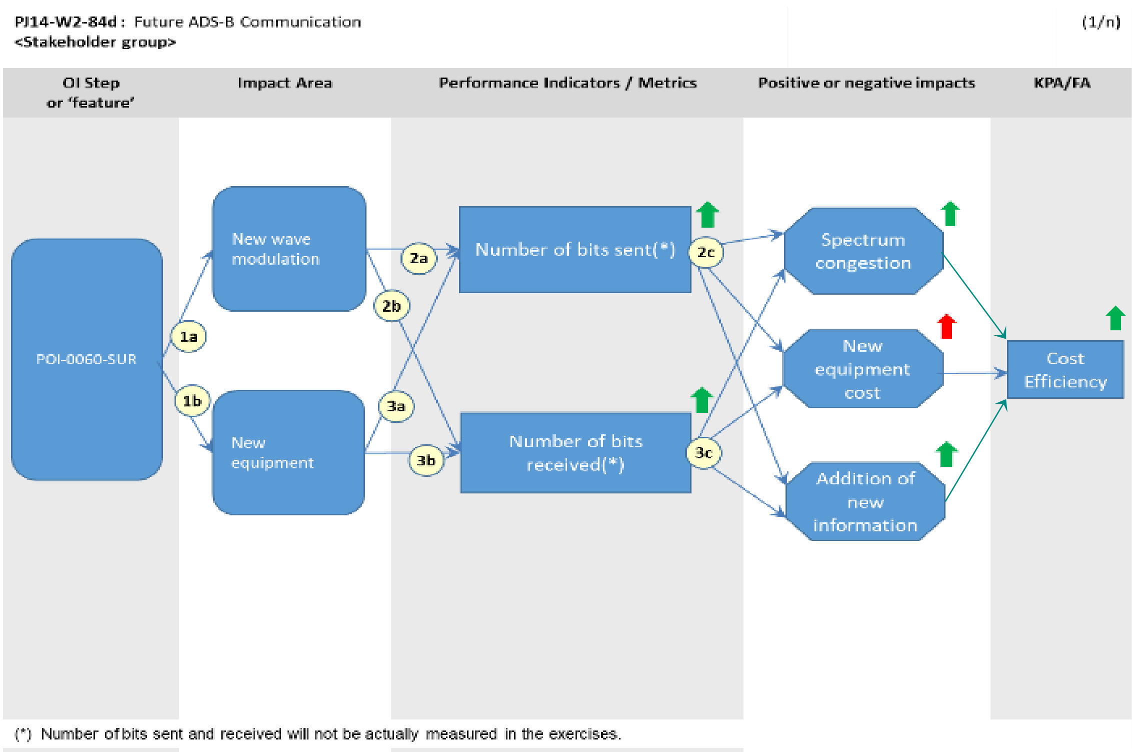


Figure 6: Benefit and Impact Mechanism (BIM) for PJ14-W2-84d

[6] The benefits are determined by converting workload reduction to a productivity improvement, and then scale it to peak traffic in the applicable sub-OE category. It has to be peak traffic because there must be demand for the additional capacity (note that in this case the assumption is that the additional capacity is used for additional traffic).

PJ.14-W2-84d will enable a new way of transmitting ADS-B messages without affecting concurrent functionalities	
(1a)	The wave modulation will change by overlaying 8PSK phase modulated information onto the PPM messages
(1b)	Specific equipment is needed to get the benefits of phase overlay: transponders and ground stations will have to be replaced for new ADS-B station and transponders
(2a)	This new modulation allows for sending more useful bits (increase the net data bits from 56 up to 204)
(2b)	This new modulation allows for receiving more useful bits (increase the net data bits from 56 up to 204)
(2c)	More useful bits allow fewer messages to be sent to have the same information, reducing spectrum congestion or additional information can be added ensuring the non-regression of the service with respect to the current way of transmitting the message (ISI). Aircrafts must be equipped (transmitter), which increases the cost of investment.
(3a)	Specific equipment is needed to encode and send more useful bits (transponder)
(3b)	Specific equipment is needed to receive and decode more useful bits (receiver)
(3c)	More useful bits allow fewer messages to be received to have the same information, reducing spectrum congestion or additional information can be added ensuring the non-regression of the service with respect to the current way of transmitting the message (ISI). ANSPs must be equipped (receiver), which increases the cost of investment.

Table 16: Benefit and Impact Mechanism (BIM) for PJ14-W2-84d

After qualitatively analysing the costs involved in the solution, it is necessary to compare them with the reference scenario; **since even no monetary benefits exist, the introduction of the Phase Overlay technology could incur savings in the current costs of the air traffic sector.**

As described in Section 4.2, one of the benefits of the Phase Overlay technology is in the security domain. The extension of available data would allow the encryption of ADS-B messages, allowing the general use of these systems in European airspace and being an alternative to systems such as Secondary Surveillance Radars (SSR) Mode A/C and Mode-S. Therefore, the following section provides an analysis of the costs that would be saved if this solution were introduced.

5.2 Quantitative cost assessment

5.2.1 ANSPs costs

According to previous sections, the ANSPs costs that should be considered can be categorised as follows:

- Pre-Implementation Costs: There are no pre-implementation costs for ANSPs, associated to Solution PJ14-W2-84d. R&D and Pre-Industrialisation costs are already incurred in the SESAR Development Phase and therefore not included in the cost assessment.

- Implementation Costs: Implementation costs are those derived by the upgrade of existing ADS-B stations. In case of new stations to be installed, as these installations would be part of the deployment plans of the corresponding ANSP in a Reference Scenario, only the difference between a current station and a Phase-Overlay capable station should be considered.

- Operating Costs: Since Solution PJ.14-W2-84d is not linked to an operational solution, estimating operating costs is a challenging task. At the moment a scenario where this technological improvement is implemented in service is partially considered, and therefore, only the costs associated with the maintenance of the systems will be estimated. With regard to these maintenance costs, the higher complexity of the Phase Overlay technology could lead to a little increase in maintenance costs. Considering that in the Reference Scenario ADS-B maintenance costs could represent a 7% of the implementation cost, these costs could increase up to 10%. When this Solution becomes operational, considering the operating costs of the current ADS-B system, it would be possible to differentiate between maintenance and service provision costs. For completion, those airspaces served by satellite-based solutions should also be considered. In this case, it is likely that the service provision costs will increase after the upgrade of the satellite constellation to be Phase Overlay capable.

5.2.1.1 ANSPs cost approach

The figures included in previous sections are estimations based on expert judgement. In any case, as it has been already mentioned, there a huge number of uncertainties that make it extremely difficult to state realistic proposals.

Due to the new security applications offered by Phase Overlay technology, further optimisation of the infrastructure is achieved in comparison to CNS infrastructure evolution opportunities assessment. The ground segment follows a profit strategy based on the savings obtained by this optimisation. The complete information is available in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2") in Section 6.

5.2.1.2 ANSPs cost assumptions

The complete list of assumptions is available in Section 3.5.3 and in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2"in Section 6). The assumptions have been converted into quantitative input feeding the CBA-model developed by Solution members.

5.2.1.3 Number of investment instances (units)

As ADS-B ground stations will provide service to different operational environments, therefore, the table from the guidelines does not apply to the PJ.14-W2-84d Solution. For example, a single ADS-B station may provide service to En-route as well as several TMAs or airports. The complete information on the investment instances is available in the ANSP Database of the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2" in Section 6).

5.2.1.4 Cost per unit

An estimate of the market price of the prototypes will be provided in order to establish an overall cost of upgrading or replacing the current systems.

The receiver is developed by Indra. Although the final market price, or the manufacturing cost of this prototype is part of the commercial strategy of the company, it is estimated from recent contracts that customers' budgets for replacing or installing their ground stations are in the range of **€100,000 - €200,000**. This price could increase or decrease when considering the specific circumstances of each contract (e.g. type of station, weather conditions at the station location, etc.). Because the Reference Scenario consists of ground stations already installed, or stations in the process of being installed, the actual cost of the Phase Overlay solution is only relevant for the upgrade of these stations. Therefore, the cost of the Phase Overlay technology involved in an ADS-B ground station is assumed to be between **5% and 15% of the total cost** of the station, considering software upgrades and cards replacement. It can be observed that Phase Overlay technology does not significantly impact on the manufacturing cost of the equipment or the price that the customer has to pay to acquire it. The reason is because the most significant cost of the solution is the non-recurring cost (development cost).

With regard to maintenance costs, the higher complexity of the Phase Overlay technology could lead to a little increase in maintenance costs. Considering that in the Reference Scenario ADS-B maintenance costs could represent a 7% of the implementation cost, **these costs could increase up to 10%.**

As described in Section 4.2, one of the benefits of the Phase Overlay technology is in the security domain. The extension of available data would allow the encryption of ADS-B messages, allowing the general use of these systems in European airspace and being an alternative to systems such as Secondary Surveillance Radars (SSR) Mode A/C and Mode-S. Therefore, the unit cost of installing an ADS-B station with Phase Overlay (or an upgrade) should be reduced by the cost savings of not installing an SSR, maintaining a surveillance layer composed of Mode-S radars simultaneously. The complete information is available in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2" in Section 6).

As ADS-B ground stations can serve different operational environments, the table from the guidelines does not apply to the PJ14-W2-84d Solution. For example, a single ADS-B station may serve En-route as well as several TMAs or airports.

5.2.2 Airport operators costs

There are no associated costs of the solution.

5.2.2.1 Airport operators cost approach

There are no associated costs of the solution

5.2.2.2 Airport operators cost assumptions

There are no associated costs of the solution

5.2.2.3 Number of investment instances (units)

There are no associated costs of the solution

5.2.2.4 Cost per unit

There are no associated costs of the solution

5.2.3 Network Manager costs

There are no associated costs of the solution

5.2.3.1 Network Manager cost approach

There are no associated costs of the solution

5.2.3.2 Network Manager cost assumptions

There are no associated costs of the solution

5.2.3.3 Network Manager cost figures

There are no associated costs of the solution

5.2.4 Airspace User costs

According to previous sections, the Airspace Users costs that should be considered can be categorised as follows:

- Pre-Implementation Costs: There are no pre-implementation costs for airspace users, associated to Solution PJ14-W2-84d.
- Implementation Costs: Implementation costs are those derived by the upgrade of existing ADS-B systems onboard (card replacement on transponder systems).
- Operating Costs: Operating Costs: Since Solution PJ14-W2-84d is not linked to an operational solution, estimating operating costs is a challenging task. At the moment a scenario where this technological improvement is implemented in service is partially considered, and therefore, only the costs associated with the maintenance of the systems will be estimated. With regard to maintenance costs, the higher complexity of the Phase Overlay technology could lead to a little increase in maintenance costs.

5.2.4.1 Airspace User cost approach

The figures included in previous sections are estimations based on expert judgement. In any case, as it has been already mentioned, there are a huge number of uncertainties that make it extremely difficult to state realistic proposals.

Following the CNS infrastructure evolution opportunities assessment scheme, as a result of the benefits obtained in the ground segment, a reduction in charges is obtained due to a lower cost of service provision. Therefore, despite the higher investment and maintenance cost of Phase Overlay transponders compared to ADS-B version 2 transponders, for airspace users there would be benefits derived from ground segment savings.

5.2.4.2 Airspace User cost assumptions

Air traffic is assumed to be the same for the solution scenario and the reference scenario. Therefore, the number of ADS-B on-board equipment will also be the same in both scenarios, and will increase as the number of aircraft increases.

The complete list of assumptions is available in Section 3.5.3 and in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2" in Section 6). The assumptions have been converted into quantitative input feeding the CBA-model developed by Solution members.

5.2.4.3 Number of investment instances (units)

The number of ADS-B transponders targeted for Phase Overlay upgrade in European airspace is equal to the number of aircraft that must have ADS-B version 2 as required by the European Commission Regulation (EU) 1207/2011 (SPI IR) and its subsequent amendments.

As explained in the reference scenario, according to Eurocontrol [21], this number reaches 89.9% of aircraft in October 2021. Therefore, the number of instances to be updated with Phase Overlay technology would reach this figure, if mandatory.

According to Eurocontrol Standard Inputs for Economic Analyses [22] and Airbus Global Market Forecast 2021-2040 , the number of aircraft in Europe in 2021 reached approximately 4950.

5.2.4.4 Cost per unit

An estimate of the market price of the prototypes will be provided in order to establish an overall cost of upgrading or replacing the current systems.

The transponder has been developed by Thales. In this case, as in the receiver, the main cost will also be non-recurring, so the current market price will not be significantly affected. Phase Overlay upgrade will be performed when a general upgrade of the Transponder will be requested due to other constraints. For example, when a new Implementation Rule for Transponder will be requested (ED73E to be replaced by ED73F). In this situation, there is no cost due to Phase Overlay implementation, because it will be a small part of global SW upgrade, and certification aspect. The major cost will be due to ED73F deployment and Phase Overlay cost will be negligible.

Even so, a market price range could be estimated. Considering only the cost of adapting the transponder to add the Phase Overlay applications, the price would be in the range of **€25,000 to €35,000**. However, if a total implementation of the equipment is necessary, including also the Phase Overlay function, the price would increase to **€65,000 to €100,000**, depending on the circumstances of the replacement of each unit.

Cost category	Scheduled Airlines (SA-M) Mainline		Scheduled Airlines (SA-R) Regional		General Aviation (GA)		Business Aviation (BA)		Rotorcraft	
	Ground locations	Airborne (air vehicles)	Ground locations	Airborne (air vehicles)	IFR	VFR	Ground	Airborne	Ground	Airborne
Pre-Implementation Costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Implementation costs	N/A	From 65k€ to 100k€	N/A	From 65k€ to 100k€	From 65k€ to 100k€	From 65k€ to 100k€	From 65k€ to 100k€	From 65k€ to 100k€	From 65k€ to 100k€	From 65k€ to 100k
Operating costs (% of installation cost)	N/A	7%	N/A	7%	7%	7%	7%	7%	7%	7%

Table 17: Cost per unit - AUs

5.2.5 Military costs

There are no associated costs of the solution

5.2.5.1 Military cost approach

There are no associated costs of the solution

5.2.5.2 Military cost assumptions

There are no associated costs of the solution

5.2.5.3 Number of investment instances (units)

There are no associated costs of the solution

5.2.5.4 Cost per unit

There are no associated costs of the solution

5.2.6 Other relevant stakeholders

No further stakeholders.

6 CBAT Model

For the PJ14-W2-84d Solution, an ad-hoc CBAT model has been developed to integrate the specific requirements of the project. This model made by the members of the solution includes the established assumptions, as well as the computations, data and sources that have been used in the assessment. A separate analysis has been made for the two stakeholders involved (ANSPs and AUs) in order to observe the differences between them, and finally obtain a total Present Value.

CBAT%20Model%20
PJ14-W2-84d%20V2.:

6.1 Data sources

The complete information is available in the CBA Model (Excel file "CBAT Model PJ14-W2-84d V2") in Section 6.

7 CBAT Results

	Value	Unit	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
ANSP	Discount Factor	-	1,0	0,9	0,9	0,8	0,7	0,7	0,6	0,6	0,5	0,5	0,5	0,4	0,4	0,4	0,3	0,3	0,3	0,3	0,3
	CAPEX PV	MEUR	2,9	2,9	2,9	2,9	2,9	2,9	2,9	2,9	2,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	OPEX PV	MEUR	0,2	0,5	0,7	0,9	1,1	1,4	1,6	1,8	2,0	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2
	CAPEX NPV	MEUR	2,9	2,7	2,5	2,3	2,1	2,0	1,8	1,7	1,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	OPEX NPV	MEUR	0,2	0,4	0,6	0,7	0,8	0,9	1,0	1,0	1,1	1,1	1,0	1,0	0,9	0,8	0,8	0,7	0,7	0,6	0,6
	PV	MEUR	3,1	3,4	3,6	3,8	4,0	4,2	4,5	4,7	4,9	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2
	NPV	MEUR	3,1	3,1	3,1	3,0	3,0	2,9	2,8	2,7	2,6	1,1	1,0	1,0	0,9	0,8	0,8	0,7	0,7	0,6	0,6
	Cumulative PV	MEUR	3,1	6,5	10,1	13,9	17,9	22,2	26,6	31,3	36,2	38,4	40,6	42,9	45,1	47,3	49,5	51,8	54,0	56,2	58,5
	Cumulative NPV	MEUR	3,1	6,2	9,3	12,3	15,3	18,2	21,0	23,7	26,4	27,5	28,5	29,5	30,4	31,2	31,9	32,6	33,3	33,9	34,4
	Value	**Unit**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**
Airspace Users	Discount Factor	-	1,00	0,93	0,86	0,79	0,74	0,68	0,63	0,58	0,54	0,50	0,46	0,43	0,40	0,37	0,34	0,32	0,29	0,27	0,25
	CAPEX PV	MEUR	-4,8	-4,8	-4,8	-4,8	-4,8	-4,8	-4,8	-4,8	-4,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	OPEX PV	MEUR	1,3	2,7	4,3	4,8	6,0	7,2	8,5	9,7	11,0	10,8	10,6	10,5	10,3	10,2	10,1	9,9	9,8	9,7	9,6
	CAPEX NPV	MEUR	-4,8	-4,5	-4,1	-3,8	-3,5	-3,3	-3,0	-2,8	-2,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	OPEX NPV	MEUR	1,3	2,5	3,7	3,8	4,4	4,9	5,3	5,7	5,9	5,4	4,9	4,5	4,1	3,7	3,4	3,1	2,9	2,6	2,4
	PV	MEUR	-3,5	-2,1	-0,5	0,0	1,2	2,4	3,7	4,9	6,2	10,8	10,6	10,5	10,3	10,2	10,1	9,9	9,8	9,7	9,6
	NPV	MEUR	-3,5	-1,9	-0,4	0,0	0,9	1,7	2,3	2,9	3,3	5,4	4,9	4,5	4,1	3,7	3,4	3,1	2,9	2,6	2,4
	Cumulative PV	MEUR	-3,5	-5,6	-6,1	-6,1	-4,8	-2,4	1,3	6,2	12,3	23,2	33,8	44,3	54,6	64,8	74,9	84,8	94,6	104,3	113,8
	Cumulative NPV	MEUR	-3,5	-5,4	-5,8	-5,8	-4,9	-3,3	-1,0	1,9	5,2	10,6	15,6	20,1	24,2	27,9	31,3	34,5	37,3	39,9	42,3
	Value	**Unit**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**
TOTAL	PV	MEUR	-0,4	1,3	3,1	3,8	5,2	6,7	8,1	9,6	11,1	13,0	12,9	12,7	12,6	12,4	12,3	12,2	12,0	11,9	11,8
	NPV	MEUR	-0,4	1,2	2,7	3,0	3,9	4,5	5,1	5,6	6,0	6,5	6,0	5,5	5,0	4,6	4,2	3,8	3,5	3,2	2,9
	Cumulative PV	MEUR	-0,4	0,9	4,0	7,8	13,1	19,8	27,9	37,5	48,5	61,6	74,4	87,2	99,7	112,1	124,4	136,6	148,6	160,5	172,3
	Cumulative NPV	MEUR	-0,4	0,8	3,5	6,5	10,4	14,9	20,0	25,6	31,6	38,1	44,1	49,5	54,5	59,1	63,3	67,1	70,6	73,8	76,8

Table 18: General results

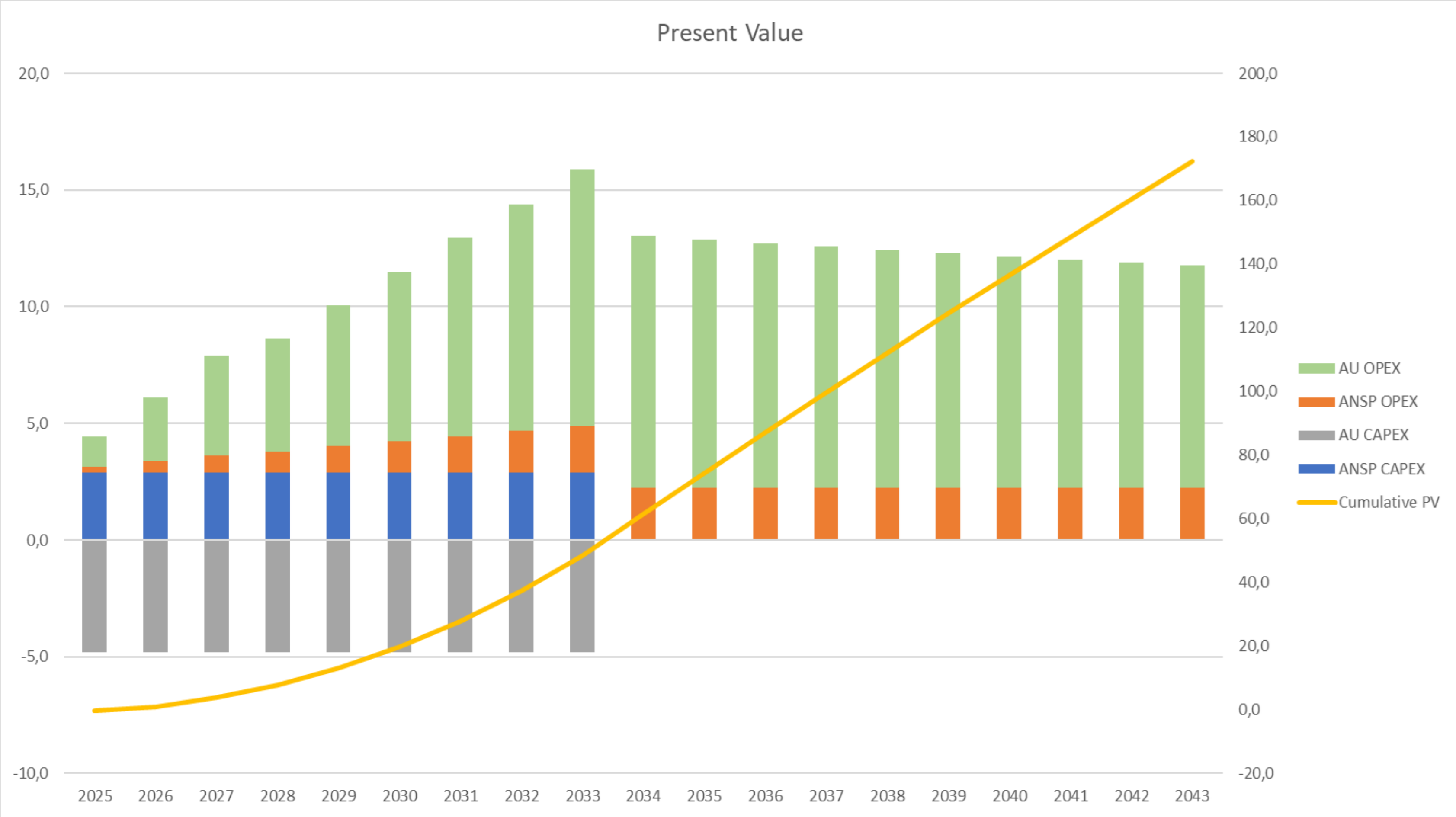


Figure 7: Present Value

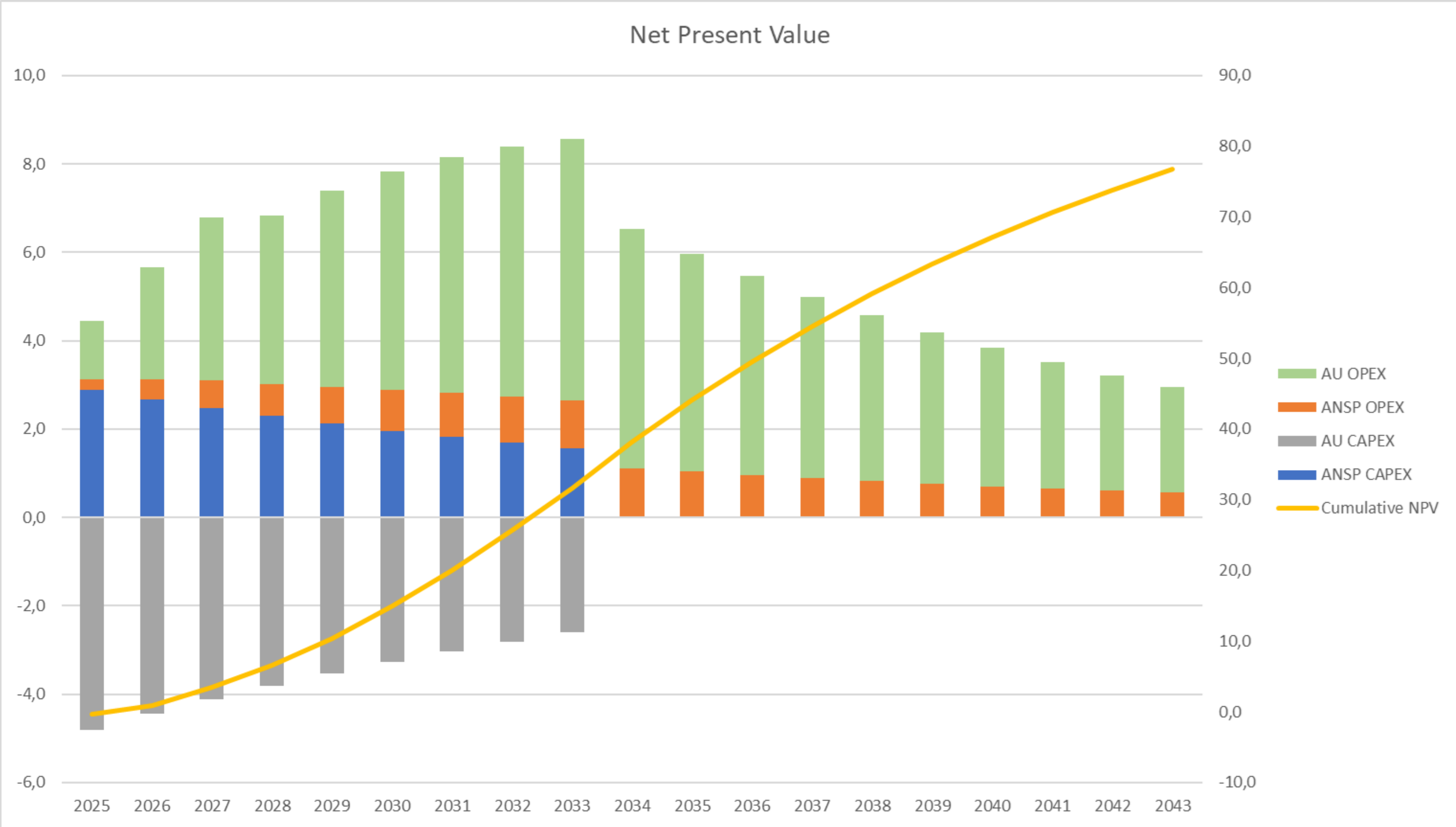


Figure 8: Net Present Value

8 Sensitivity and risk analysis

Due to the difference nature between the stakeholders (because of different assumptions and data), it has been decided to conduct a separate sensitivity analysis, in order to obtain realistic and contrasted information on the impact that the assumed inputs may have on the final result of the Cost Benefit Analysis.

Therefore, the following sections will analyse each stakeholder separately, ANSPs and AUs; concluding which inputs have the most impact on the final outcome.

8.1 ANSPs analysis

8.1.1 Influence of the discount rate on NPV

The following graph is extracted from the CBAT model and depicts the impact of the Discount rate on the ANSPs NPV.

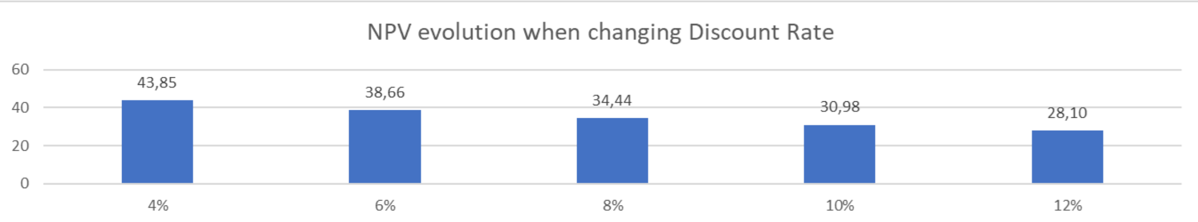


Figure 9: SESAR Solution PJ.14-W2-84d NPV and Discount Rate (ANSPs)

8.1.2 Variation of the input to the CBAT model

As this CBAT is built upon several assumptions, the approach chosen for the sensitivity analysis is to vary the strongest assumptions (ranges +/- 25% and +/- 50% applied) and see their individual impact/influence on e.g. the NPV. The main uncertainties for ANSPs are:

- The discount rate proposed by SJU.
- The cost of maintenance of new ADS-B stations with Phase Overlay.
- Avoided number of Mode S stations in Solution Scenario compared with Reference Scenario due to the further infrastructure optimisation by implementing security applications of Phase Overlay.
- The added cost of ADS-B stations with Phase Overlay technology compared to the cost of ADS-B stations without Phase Overlay.
- New number of ADS-B stations in Solution Scenario compared with the Reference Scenario in order to replace avoided number of Mode S stations.

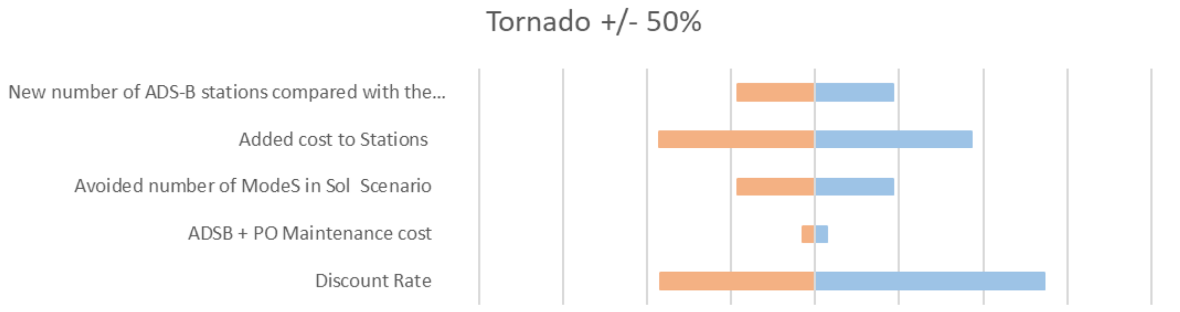
The figures below show that only the added cost of ADS-B stations with Phase Overlay technology assumption has a significant impact on the level of confidence of the CBAT (regardless of discount rate). Nevertheless, the ASNPs NPV remains always positive.

	Net Present Value				
	Discount Rate	ADSB + PO Maintenance cost	Avoided number of ModeS in Sol Scenario	Added cost to Stations	New number of ADS-B stations compared with the reference scenario
-50%	43,85	34,94	37,64	40,85	37,64
-25%	38,66	34,69	36,04	37,65	36,04
Baseline	34,44	34,44	34,44	34,44	34,44
25%	30,98	34,20	32,84	31,24	32,84
50%	28,10	33,95	31,25	28,04	31,25

	Net Present Value VARIATION				
	Discount Rate	ADSB + PO Maintenance cost	Avoided number of ModeS in Sol Scenario	Added cost to Stations	New number of ADS-B stations compared with the reference scenario
-50%	27%	1%	9%	19%	9%
-25%	12%	1%	5%	9%	5%
Baseline	0%	0%	0%	0%	0%
25%	-10%	-1%	-5%	-9%	-5%
50%	-18%	-1%	-9%	-19%	-9%

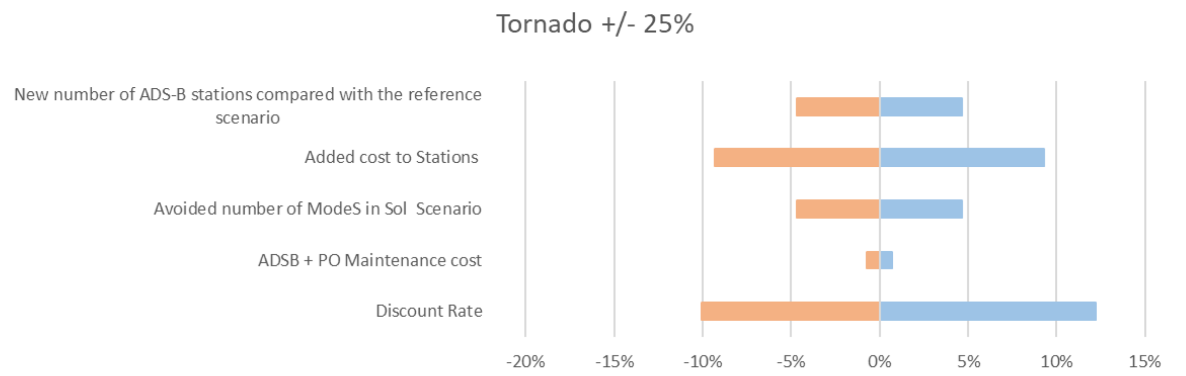
Table 19: Net Present Value (NPV) deviations for ANSPs analysis.

The following graphs are also extracted from the CBAT model and depict the impact of a variation of the input to the model (input variations +/- 25% and +/- 50%) on the NPV.



	Discount Rate	ADSB + PO Maintenance cost	Avoided number of ModeS in Sol Scenario	Added cost to Stations	New number of ADS-B stations compared with the reference scenario
+50%	-18%	-1%	-9%	-19%	-9%
-50%	27%	1%	9%	19%	9%

Figure 10: Tornado graph +/- 50%



	Discount Rate	ADSB + PO Maintenance cost	Avoided number of ModeS in Sol Scenario	Added cost to Stations	New number of ADS-B stations compared with the reference scenario
+25%	-10%	-1%	-5%	-9%	-5%
-25%	12%	1%	5%	9%	5%

Figure 11: Tornado graph +/- 25%

8.2 AUs analysis

8.2.1 Influence of the discount rate on NPV

The following graph is extracted from the CBAT model and depicts the impact of the Discount rate on the NPV.

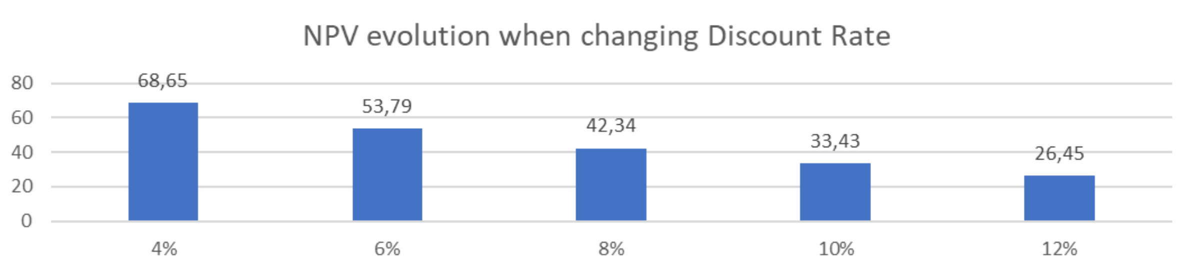


Figure 12: SESAR Solution PJ.14-W2-84d NPV and Discount Rate (AUs)

8.2.2 Variation of the input to the CBAT model

As in the ANSPs sensitivity analysis, the strongest assumptions will be varied in order to see their individual impact/influence on e.g. the NPV. The main uncertainties for AUs are:

- The discount rate proposed by SJU.
- The discount in service provision fees per flight due to the profit achieved in the ground segment (ANSPs analysis).
- The traffic evolution rate provided by EUROCONTROL in Challenges of Growth - Annex 1 - Flight Forecast to 2040 [23].
- The added cost of ADS-B transponder with Phase Overlay technology compared to the cost of ADS-B transponder without Phase Overlay.

The figures below show that these assumptions have a significant impact on the level of confidence of the CBA.

Net Present Value	Discount Rate	Saving fees	Traffic evolution	Added cost of ADS-B V3
-50%	68,65	-4,31	38,13	64,32
-25%	53,79	19,01	40,21	53,33
Baseline	42,34	42,34	42,34	42,34
25%	33,43	65,66	44,53	31,35
50%	26,45	88,99	46,77	20,36

Net Present Value VARIATION	Discount Rate	Saving fees	Traffic evolution	Added cost of ADS-B V3
-50%	62%	-110%	-10%	52%
-25%	27%	-55%	-5%	26%
Baseline	0%	0%	0%	0%
25%	-21%	55%	5%	-26%
50%	-38%	110%	10%	-52%

Table 20: Net Present Value (NPV) deviations for AUs analysis.

The following graphs are also extracted from the CBAT model and depict the impact of a variation of the input to the model (input variations +/- 25% and +/- 50%) on the NPV.

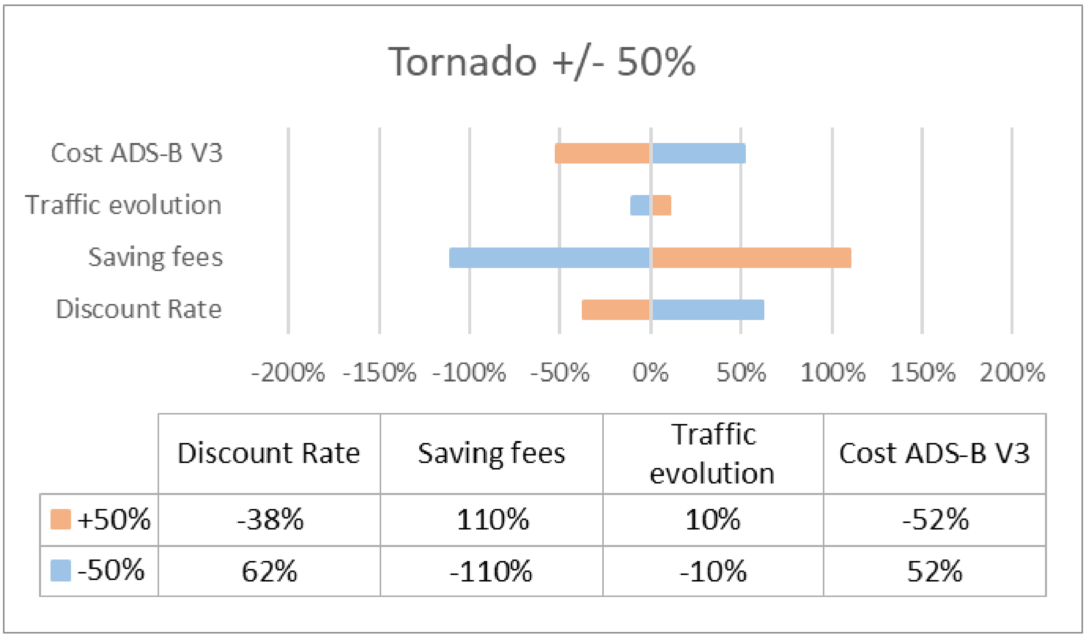
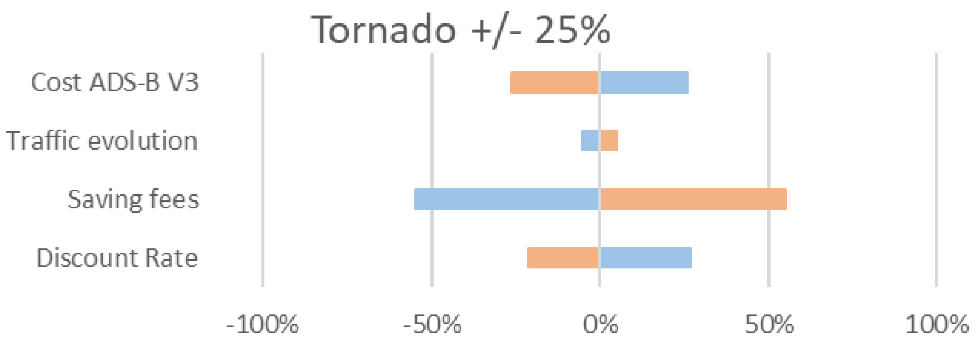


Figure 13: Tornado graph +/- 50%



	Discount Rate	Saving fees	Traffic evolution	Cost ADS-B V3
+25%	-21%	55%	5%	-26%
-25%	27%	-55%	-5%	26%

Figure 14: Tornado graph +/- 25%

The discount in service provision fees per flight have a major impact on the final result, and at the same time are directly dependent on the ANSP analysis. That is why the airspace analysis only serves as feedback on the outputs that influence, as well as on the expected future evolution of this stakeholder. However, given the CNS Advisory Group's reduction in fees of EUR 6 per flight, and estimating the infrastructure optimisation in the solution scenario, the assumption of reducing these fees by only EUR 1 per flight may be conservative. This difference in the statement is due to the fact that the scope of the CNS advisory group is wider, as it considers an optimisation of the infrastructure not only in surveillance, but also in communication and navigation systems.

For all these reasons, this AUs analysis should not be taken as truthful, but as an orientation exercise to get an overview of where this solution would have an economic impact.

9 Recommendations and next steps

Since PJ14-W2-84d is a technological solution, **it is recommended to find a link to an operational solution** in order to quantify the benefits, costs and impact of the Phase Overlay technology in an operational environment. The technological solution also results in the CBAT analysis being based on strong assumptions, which could lead to the final results changing significantly in the future. Therefore, **this analysis should be taken mainly as an orientation exercise to get an overview of where this solution would have an economic impact.**

According to the three benefits of this Solution (additional information transmission, reduced spectrum congestion and the possibility of adding a security layer to the ADS-B message), the impact Phase Overlay could have in the future encompasses both technological and operational improvements. Being at an early stage of the deployment, and not yet having a concrete operational link and also not having a complete definition in the standards, it is difficult to give realistic values of the economic impact that Phase Overlay could have. However, for each of the benefits could be deducted:

- Additional information transmission: Although this benefit does not imply a high direct economic impact because the information does not generate tangible profit, it provides an increase in data capacity that enables the use of new information for applications that have a real economic impact, as explained below.

- Security applications: the use of the additional data capacity of the Phase Overlay message for security applications such as encryption or authentication, allows an extended use of ADS-B technology in fields where there was resistance for its deployment. For example, in military aviation, the aircraft's position is an extremely sensitive information that can not be openly available. Due to the encryption of ADS-B messages by Phase Overlay, and the fact that the information it contains is only accessible to those to whom it is intended, military aviation could increase its confidence in ADS-B systems, moving towards an optimisation of the ground infrastructure in parallel with civil aviation. This benefit would therefore have a high economic impact and will be further studied in the SESAR3 programme.

- Spectrum efficiency: could lead to an increase in capacity (or at least to avoid a limitation in a future growth due to an unacceptable spectrum congestion). It could therefore have a high economic impact, which would not be in the form of benefits, but by avoiding the losses that would result from a detriment to air traffic growth and airspace capacity as a consequence of spectrum congestion.

On the other hand, this analysis is based on the exploitation of one of the possible benefits of the Phase Overlay: the security. This benefit needs to be further studied; therefore, a **next step would be continue developing Phase Overlay technology in future projects to better define applications in the security field, in coordination with standardisation bodies.**

As the technological study of Phase Overlay has already achieved TRL6, the following steps are the industrialization and deployment phases. Nevertheless, Phase Overlay is not completely defined, as it is feasible at a technical and physical level, but its content and applications are not well defined.

For that reason, in line with the information stated in the D12.4.400 TVALR deliverable [19], **this Solution proposes and recommends the creation of a new SESAR3 project dedicated to study the**

potential operational applications of this new modulation, such as cybersecurity, and introduce new contents into the new data available that could be beneficial for controllers and ANSP. The execution of flight tests will be needed to validate this concept operationally.

In addition, it is recommended to **work closely with the standardisation bodies** that are defining this technology, such as EUROCAE WG51-SG4. This will help to follow the evolution of this technology in the standards (ED-102B / DO-260C), in order to include security applications.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

10 References and Applicable Documents

10.1 Applicable Documents

[1] SESAR 2020 Project Handbook v2.0 for W2

[2] Guidelines for Producing Benefit and Impact Mechanisms

[3] Methods to Assess Costs and Monetise Benefits

[4] SESAR 2020 Cost-Benefit Analysis Model

[5] Cost Benefit Analyses – Standard Input

[6] Cost Benefit Analyses – Method to assess costs

[7] ATM CBA Quality checklist

[8] Methods to Assess Costs and Benefits for CBAs

10.2 Reference Documents

[9] Common assumptions

[10] CNS Infrastructure Evolution Opportunities, CNS Advisory Group: https://www.eurocontrol.int/sites/default/files/2021-06/eurocontrol-cns-infra-evolution-opportunities.pdf

[11] European ATM Master Plan Portal https://www.atmmasterplan.eu/

[12] Performance Framework

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11 Appendix

Mapping between ATM Master Plan Performance Ambition KPAs and SESAR 2020 Performance Framework KPAs, Focus Areas and KPIs, source reference *[12]*

ATM Master Plan SESAR Performance Ambition KPA	ATM Master Plan SESAR Performance Ambition KPI	Performance Framework KPA	Focus Area	#KPI / (#PI) / <Design goal>	KPI definition
Cost efficiency	PA1 - 30-40% reduction in ANS costs per flight	Cost efficiency	ANS Cost efficiency	CEF2	Flights per ATCO hour on duty
				CEF3	Technology Cost per flight
Capacity	PA7 - System able to handle 80-100% more traffic	Capacity	Airspace capacity	CAP1	TMA throughput, in challenging airspace, per unit time
				CAP2	En-route throughput, in challenging airspace, per unit time
	PA6 - 5-10% additional flights at congested airports		Airport capacity	CAP3	Peak Runway Throughput (Mixed Mode)
			Capacity resilience	<RES1>	% Loss of airport capacity avoided
				<RES2>	% Loss of airspace capacity avoided
	PA4 - 10-30% reduction in departure delays	Predictability and punctuality	Departure punctuality	PUN1	% of Flights departing (Actual Off-Block Time) within +/- 3 minutes of Scheduled Off-Block Time after accounting for ATM and weather related delay causes

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ATM Master Plan SESAR Performance Ambition KPA	ATM Master Plan SESAR Performance Ambition KPI	Performance Framework KPA	Focus Area	#KPI / (#PI) / <Design goal>	KPI definition
Operational Efficiency	PA5 - Arrival predictability: 2 minute time window for 70% of flights actually arriving at gate		Variance of actual and reference business trajectories	PRD1	Variance of differences between actual and flight plan or Reference Business Trajectory (RBT) durations
	PA2 - 3-6% reduction in flight time	Environment	Fuel efficiency	(FEFF3)	Reduction in average flight duration
	PA3 - 5-10% reduction in fuel burn			FEFF1	Average fuel burn per flight
Environment	PA8 - 5-10% reduction in CO_2 emissions			(FEFF2)	CO_2 Emissions
Safety	PA9 - Safety improvement by a factor 3-4	Safety	Accidents/incidents with ATM contribution	<SAF1>	Total number of fatal accidents and incidents
Security	PA10 - No increase in ATM related security incidents resulting in traffic disruptions	Security	Self- Protection of the ATM System / Collaborative Support	(SEC1)	Personnel (safety) risk after mitigation
				(SEC2)	Capacity risk after mitigation
				(SEC3)	Economic risk after mitigation
				(SEC4)	Military mission effectiveness risk after mitigation

Table 21: Mapping between ATM Master Plan Performance Ambition KPAs and SESAR 2020 Performance Framework KPAs, Focus Areas and KPIs

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