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D12.3.500 - PJ.14-W2-84c - TRL6 CBAT - Secured Surveillance Systems (Single and Composite Systems)

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PJ.14-W2-I-CNSS

PJ.14-W2-84C - TRL6 - SECURED SURVEILLANCE SYSTEMS (SINGLE AND COMPOSITE SYSTEMS)

This CBA is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement No 874478 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document provides the **Technical Cost Benefit Analysis r**elated to SESAR Solution PJ.14-W2-84c addressing the secured surveillance systems.

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 Cost Benefit Analysis (CBA) related to the deployment of SESAR Solution 84c.

The aim of this solution PJ.14-W2-84c, is to increase the maturity level of the enabler (CTE-S09) to a TRL6 by validating the security concept at Single and Composite (ADS-B+WAM) sensor level. PJ.14-W2-84c develops secured surveillance systems (focus on cooperative and cooperative dependent sensors) enabling the operational use of security functions. The scope covers the sensor-based radio frequency related threat detection and validation capabilities, performance assessment and identification of interoperable detection forwarding mechanisms by a specific ASTERIX target validation message. With the specific objective to increase the maturity towards TRL6 a specific focus is laid on standardization including the ASTERIX target validation message (ASTERIX CAT 246).

The provision of a new security functionalities for ground surveillance sensors, allowing detection of RF-related threats with a specified performance and report the existence of them to system users, is seen as enabler to use ADS-B as an independent surveillance layer also in high density airspace like in ECAC.

ADS-B provides a high update rate, generally high accuracy surveillance in a cost-effective way. ADS-B position information is continuously broadcast by the airspace user to the ground segment. In order to use ADS-B to derive separation related decisions the confidence in the received information needs to be ensured. The secured ADS-B performs anomaly detection and target validation to achieve this goal. Target validation can be performed against a different sensor (like SSR or WAM) or performed within the ADS-B based on evaluation of physical measurements of the radio signals received which are linked to the airspace user position. This mechanism allows to validate that the reported airspace user position conforms with the origin of the transmitted RF-signal.

When using ADS-B as an independent surveillance layer, the resulting benefits are related to infrastructure optimisation. In this manner, the technical cost-benefits assessment shows similarities to the one performed by PJ.14-W2-84d for the ADS-B phase overlay. In order to avoid confusion, differences and similarities are discussed below. Both solutions complement each other.

Solution PJ.14-W2-84d works on the implementation of a new ADS-B transmission standard, which primarily allows to increase the message capacity, what provides the benefit of a reduced spectral congestion. In addition, it allows to implement authentication and encryption schemes which would allow to increase the security of the transmission. With this background, solution PJ.14-W2-84d assessed a reduction of Mode-S radars.

The primary focus of the present solution PJ.14-W2-84c is on the security of ADS-B itself. An increased integrity of the data provided by ADS-B allows to use ADS-B as an independent surveillance layer through increased trust in received data. This in turn allows to reduce surveillance redundancy by reducing existing Mode-S radars.

The solution scenarios considered in the CBATs of the two solutions are different: PJ.14-W2-84d refers to a new standard, affecting ground and airborne equipment. While PJ.14-W2-84c solely looks onto ground equipment. Therefore, the applied figures differ and also the resulting benefits are achieved independently by the two solutions.

The benefit mechanism (reduction of Mode-S radars) applied by the two solutions is identical for the present CBATs. Therefore, certain underlying assumptions are identical. But the rest of the two solution benefits is different.

The CBAT for solution 84c is independent, meaning that the benefit is standing on its own and is just valid exclusively for this solution. The calculus has been done solely solution 84c.

If both solutions would be implemented at the same time a specific CBAT should be performed considering also specific aspects relevant for the actual implementation.

One potential benefit of PJ.14-W2-84d is the increased data capacity which paves a path to secure the transmission – inhibiting 'Man-in-the-Middle' – kind of security risks. The study of this Phase Overlay potential application was proposed by the PJ.14-W2-84d Solution as a recommendation for future SESAR projects, especially with the definition of a protocol to authenticate the origin of the transmission and to encrypt the data transfer.

PJ.14-W2-84c has its focus on securing the data content. It secures information by applying means of physical security – inhibiting security risks originating at the source and provides an interoperable mean to forward security related information.

With these differences the implementation should be assessed independently and according to local needs.

However, in general it is recommendable to envisage the implementation of both solutions because different aspects would be resolved: spectral congestion with 84d and data integrity with 84c.

As a result of the CBAT of PJ.14-W2-84c, it was found that the application of the secured surveillance provides cost savings as benefit compared to the reference scenario applying legacy ADS-B ground sensors.

2 Introduction

2.1 Purpose of the document

This document provides the Cost Benefit Analysis (CBA) related to SESAR Solution PJ14-W2-84c that has been validated during validation activities at a TRL6 level. As a technical solution PJ14-W2-84c is not linked to an operational solution. The benefits result from cost savings (CEF3) compared to the reference solution.

2.2 Scope

This document provides the Cost Benefit Analysis (CBA) related to SESAR Solution PJ14-W2-84c at TRL6 level.

It covers the benefits resulting from cost-savings (CEF3) by ECAC wide deployment of secured surveillance sensors developed by the solution in comparison to state-of-the-art En-route and TMA surveillance.

2.3 Intended readership

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.
- **Section 4** describes the foreseen benefits of the solution scenario.
- **Section 5** provides a cost assessment.
- **Section 6** provides the Solution 84c ad-hoc CBAT model.
- **Section 7** provides the results of CBAT model in section 6.

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- **Section 8** provides the sensitivity analysis 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

This Solution is the direct continuation of the Solution PJ.14-04-03 Task 5 which reached TRL4 during Wave 1. Rather than a formal and quantitative CBA, PJ.14-04-03 Task 5 developed and delivered a qualitative High-Level Economic Appraisal at the end of the previous phase. The conclusions and remarks of the document are still considered applicable.

2.6 Glossary of terms

Term	Definition	Source of the definition
ACAS	An aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders	*ICAO Doc 4444*
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 Annex 10*
Aircraft Address	A unique combination of 24 bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance	*ICAO Doc 4444*
Capital Expenditure	Capital expenditures (Capex) are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment.	*Investopedia*
Cost benefit analysis	A cost-benefit analysis is a systematic process that businesses use to analyse	*Investopedia*

	which decisions to make and which to forgo. The cost-benefit analyst sums the potential rewards expected from a situation or action and then subtracts the total costs associated with taking that action.	
Mode-**A/C**	Surveillance radar system which uses transmitters/receivers (interrogators) where the aircraft transponder sends back a reply containing a temporary code (Mode A) and a flight level (when combined with mode C).	*Based on* SKYbrary
Mode-S	Surveillance radar which uses transmitters/receivers (interrogators) where the transponder sends back a reply containing a code, flight level and other information, e.g. aircraft identification, selected level, etc.	*Based on* SKYbrary
Net Present Value	Net Present Value (NPV) is the sum of all discounted cash inflows and outflows during the time horizon period.	*Investopedia*
Operational expenditure	An operational expenditure (Opex) is an expense a business incurs through its normal business operations.	*Investopedia*
Reference scenario	To measure the performance impact of a SESAR Solution, at least two different situations must be assessed and compared: a Reference Scenario and a Solution Scenario. One situation should be a scenario that does not have the concept element (the reference scenario) and, then, a second situation that equals the first except that it includes the new concept element (the Solution scenario). The descriptions of the reference scenario(s) and of the solution scenario(s) can include, depending on the scope of the validation exercise, airport information, airspace information, traffic information, etc.	*SESAR 2020 Performance Framework* *TVALP Template guidances*

	The reference scenario is matched in time with the solution scenario but DOES NOT include the SESAR solution(s) that is the subject of the validation. The only difference between the solution and the reference scenario is that the former includes the SESAR solution(s) that is the subject of the validation.	
Sensitivity analysis	Sensitivity analysis determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. In other words, sensitivity analyses study how various sources of uncertainty in a mathematical model contribute to the model's overall uncertainty. This technique is used within specific boundaries that depend on one or more input variables.	*Investopedia*
Siting	To situate or locate on a site	*thefreedictionary*
Solution scenario	See Reference scenario	*SESAR 2020 Performance Framework* *TVALP Template guidances*
SSR	A surveillance radar system which uses transmitters / receivers (interrogators) and transponders	*ICAO Annex 10*

Table 2-1: Glossary of terms

2.7 List of Acronyms

Term	Definition
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance - Broadcast
ASTERIX	All-purpose structured EUROCONTROL surveillance information exchange
ATM	Air Traffic Management
ATC	Air Traffic Control

ATS	Air Traffic Services
CAT	Category
CBA	Cost-Benefit Assessment
CBAT	Cost-Benefit assessment Technological
CNS	Communication Navigation Surveillance
ENs	Enablers
ER	En-Route
FRD	Functional Requirements Documents
GPS	Global Positioning System
GS	Ground Station
ICAO	International Civil Aviation Organization
IRS	Interface Requirements Specification
MLAT	Multilateration
MOPS	Minimum Operational Performance Standards
NPV	Net Present Value
NRC	Non Recurring Costs
REQ	Requirement
RF	Radio Frequency
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SSR	Secondary Surveillance Radar
SUR	Surveillance
SUT	System Under Test
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level
TS	Technical Specification

TVALP	Technical Validation Plan
V&V	Validation and Verification
WAM	Wide Area Multilateration

Table 2-2: List of acronyms

3 Objectives and scope of the CBA

3.1 Problem addressed by the solution

The solution PJ14-W2-84c develops a secured cooperative surveillance sensor providing surveillance service for En-route and TMA airspace to detect potential RF-related threats (like jamming and spoofing) especially to ADS-B to increase the confidence of the controller in the received information. SESAR research covers detection of related threats with a specified performance and forwarding information in an interoperable manner via specific ASTERIX categories.

The present CBA assesses the costs and benefits by the solution through comparison against a reference scenario. The reference is formed by using ADS-B with SSR as defined by current standards, whereas the solution scenario covers the reduced SSR infrastructure with applying secured ADS-B developed by PJ.14 -W2-84c.

3.2 SESAR Solution description

The goal of solution 84c is to develop secured surveillance functionality, enabling the detection, reporting and when possible mitigation of security threats of different nature that could affect to the surveillance chain (CTE-S9).

Development of secured surveillance systems (focus on cooperative independent and dependent sensors) enabling the operational use of security functions.

The scope covers the sensor-based radio frequency related threat detection and validation capabilities, performance assessment and identification of interoperable detection forwarding mechanisms by a specific ASTERIX target validation message.

The ADS-B is a cooperative & dependent system. Due to its RF-interface and modulation scheme it is vulnerable to be interfered as any other RF-based system. In addition, target reports may be modified or even supressed in a relatively easy way. Taking into account that ADS-B is a crucial piece of the surveillance infrastructure in the coming years, this system needs to be secure against any type of threat entering from the outside via the RF signal and also from the network side the latter is separately covered by cyber-security.

Implementing new security functionalities can facilitate the detection and implementation of different threats similar to working together with a multilateration system.

This PJ.14-W2-84c provides analysis of the potential threats of this system, explaining how to detect and report them. The responsibility of the security function at ADS-B ground sensor level is primarily to detect and report an existing threat condition. Enhancements towards a mitigation for a “clean” aerial situation display at CWP needs the involvement of additional validation means either at the ground sensor or further processing steps which typically are part of the downstream ATC data processing chain.

In consequence securing the ADS-B data enhances safety by making all the information shown to the controller more trustworthy. ADS-B systems with security features represent a solution for high density airspace, allowing to gain operational benefits (i.e. accuracy & update rate) using ADS-B as independent surveillance layer

Solution 84c is part of a panel of surveillance solutions defined in the scope of PJ.14 that has to be performed to reach maturity TRL6 of this solution.

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-W2-84c	POI-0059-SUR	Securing the ADS-B data enhances safety by making the information provided to the controller more trustworthy. The secured ADS-B data can be used for high density airspace as independent surveillance layer providing more accurate data with higher refresh rate.	Fully	EATMA DS23 Draft

Table 3-1: SESAR Solution PJ14-W2-84c Scope and related OI steps

OI Steps ref.	Enabler[1] ref.	Enabler definition	Enabler coverage	Applicable stakeholder	Source reference
POI-0059-SUR	CTE-S09	Secured surveillance functionality enables the detection, reporting	Fully	Air Navigation Service Provider ANSP-CIV-CNS	EATMA DS23 Draft

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

		and when possible mitigation of security threats of different nature that could affect to the surveillance chain.		ANSP-MIL-CNS	

Table 3-2: OI steps and related Enablers

3.3 Objectives of the CBA

This document provides the Cost Benefit Analysis (CBA) related to the deployment of the SESAR technological solution PJ.14-W2-84c that has been matured through validation activities at TRL6 level. The main purpose of this CBA is to facilitate and support better informed decision-making for key investment decisions. This is achieved by:

- identifying all costs and benefits per stakeholders,
- quantifying in economic terms the costs and benefits,
- calculating the economic value of the project,
- making a cash flow projection,
- Identifying the factors/assumptions having the most influence on the results

3.4 Stakeholders[2] identification

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

Stakeholder	**The type of stakeholder and/or applicable sub-OE**	**Type of Impact**	**Involvement in the analysis**	**Quantitative results available in the current CBA version**
ANSP	ER, TMA, (TWR)	Invest: Purchase, install and bring to operation SecSUR Enjoy benefit: lower total cost of ownership compared to reference (full SSR infrastructure)	Yes	Yes on both costs and benefits
Airport Operators			No	
Network Manager			No	
Scheduled Airlines (Mainline and Regional)			No	
Business Aviation			No	
Rotorcraft			No	
General Aviation IFR			No	
General Aviation VFR			No	
Military – Airborne			No	
Military – Ground			Potentially yes	Secured ADS-B is a cost-efficient

[2] 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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			Not assessed	high performance surveillance mean. As a 'general purpose' surveillance it is assumed to be of interest for military application as well. The use of distinct military transmission can be reduced during non-critical operations. Since the application in military context is not clear no assessment was performed.
Other impacted stakeholders (ground handling, weather forecast service provider, NSA....)			No	

Table 3-3: SESAR Solution PJ14-W2-84c CBA Stakeholders and impacts

All costs are attributed to ANSPs and no costs for Airspace Users.

3.5 CBA Scenarios and Assumptions

The CBA aims to provide results at ECAC level about the economic and financial viability of deploying the SESAR Solution PJ.14-W2-84c at European scale.

Scope: The assessment will consider the application of secured surveillance in ECAC ER and TMA airspace. The assessment will cover the cost and benefits provided by secured surveillance sensor. As a technical solution PJ.14-W2-84c will not assess operational benefits. For this assessment the benefit of increased security through increased confidence in ADS-B surveillance data results in the potential to rationalise the surveillance infrastructure, i.e. by reducing the number of Mode-S radars.

This approach is very similar to the one applied by solution PJ.14-W2-84d, where in [12] it is considered: "*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 multi-radar coverage will be substituted by a multi-sensor 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.*"

While solution PJ.14-W2-84d introduces an extended modulation scheme, which provides a future path for the introduction of air-to-ground security (authentication) methods in ADS-B, PJ.14-W2-84c focuses on the validation of the provided (position) information by the ground sensor. The validation by the ground sensor is independent from the airborne segment and does also not require any changes to the airborne implementations. In fact, it is assumed that no changes to the airborne ADS-B implementation is performed. The security functionality in the ground sensor allows for an independent verification that the information received from the airborne segment is correct. This is similar to validation with an external sensor (SSR or MLAT). Therefore, both solutions (84d and 84c) are not in opposition to each other.

In consequence the present CBAT for PJ.14-W2-84c Secured Surveillance will orient on the approach taken by PJ.14-W2-84d to ensure comparability and consistency. Hence also for solution PJ.14-W2-84c a back-up infrastructure of SSRs will be considered.

The resulting benefit of PJ.14-W2-84c Secured Surveillance is cost saving resulting from the reduction in the number of Mode-S Secondary Surveillance Radars and the cost for Secured ADS-B sensors.

The Main KPI addressed by solution is CEF3.

3.5.1 Reference Scenario

The reference scenario is represented by an airspace where ADS-B as per existing airborne standards (DO-260 … DO-260B) is in operation.

ADS-B ground sensors do not apply RF-security functionality. Mode-S radars are deployed, covering the entire relevant airspace.

Figures for equipage percentage and number of deployed systems are based on Eurocontrol data [14]

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

Table 3-4: Expected facilities at ECAC level for Reference Scenario.

As also in [13] in the Reference Scenario, a decreasing tendency in the number of Mode A/C and Mode S radars is considered, while the number of ADS-B sensors is forecast to increase.

3.5.2 Solution Scenario

The solution scenario considers the Secured Surveillance sensor developed by solution PJ14-W2-84c to be applied for ER and TMA airspace.

Compared to legacy ADS-B ground infrastructure mainly software modifications and some limited hardware additions have to be performed. Examples for the hardware modifications are changed receive antennas, addition of interrogators or denser siting of the ground stations. It is assumed that only one of the hardware means is applied per ground station and the complete validation capability will result when multiple ground stations work together.

The hardware addition is reflected by adding 10% to 20% to the cost of an ADS-B ground station.

It is assumed the secured ADS-B infrastructure is implemented in a forward fit manner. Deployment will then occur either due to the grow (new ADS-B stations) or replacement of existing ones with secured ADS-B ground stations as part of the normal lifecycle replacements.

Geographical scope: The solution is assumed to be deployed ECAC wide

Following ref. [9] regarding the discount rate a value of 8% is considered. The discount rate will be subject to variation assessment.

The same discount rate is applicable to reference and solution scenario.

Traffic evolution: The traffic evolution usually takes values from the latest STATFOR Long-term Forecast, which is used as input to define the Common Assumptions in [8]. However, it affects the solution deployment indirectly via the demand to increase the ADS-B ground station network.

ECAC Area	SURVEILLANCE		
Facility (Units)	Mode A/C	Mode S	MLAT/ADS-B
Current Network	150	325	1059
Future MON	0	140	1250

Table 3-5: Expected facilities at ECAC level for Solution Scenario.

The time-horizon of the CBA including development, deployment and operational timeframes of the solutions is based on information as covered in EATMA and complemented with progress made by the solution in wave 2.

According to EATMA, DS23 draft the following dates apply:

V5 Start: 31-12-2024
IOC: 31-12-2026
FOC: 31-12-2030

The graphical representation of the timeline is provided in figure 3-1

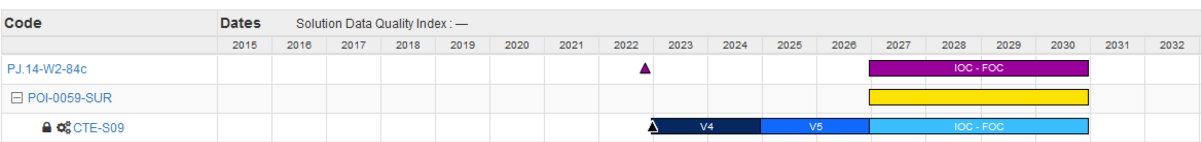

Figure 3-1: Timeline defined in EATMA

Considering the technological progress, progress made by standardisation to establish extended standards covering the secured surveillance and the new ASTERIX CAT246 and considering the forward fit replacement the timeline as shown in figure 3-2 will be taken into account for this CBA.

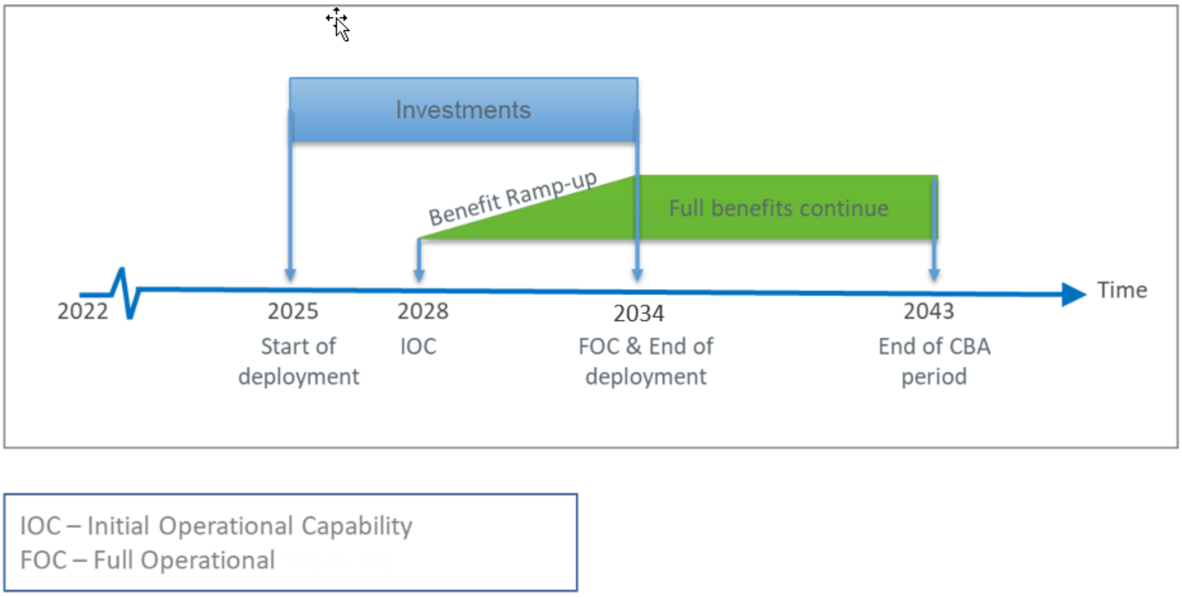

Figure 3-2: Timeline considered for this CBA

3.5.3 Assumptions

It is assumed that standardisation and system industrialization are mature at the time of IOC

Assuming a linear growth rate the assumed yearly equipage increase is 10%/year, resulting in 28 stations / year with end of deployment by 2034.

An HW exchange occurs typically approximately every 10 years. Here it is assumed the total deployed base of 1119 ground stations will be replaced over the next 10 years, resulting in 112 ground stations per year which will be exchange in the frame of normal lifecycle replacements. Life cycle replacements after FOC will not be considered in this CBAT.

It is assumed that the cost for improved hardware capabilities are 5% to 10% of an ADS-B ground station without security functions. The security functions represent mainly SW-changes in the ground station firmware and the central processing plus very limited HW modifications to some (not all) ground stations.

It is assumed that the increase in air traffic together with infrastructure rationalisation leads to increased number of ADS-B ground stations compared to the reference scenario. This increased number of ground stations can be fully applied to secured surveillance function.

A linear grow is assumed for the deployment of secured ADS-B.

Yearly maintenance cost is assumed to be 7% of installation cost. Maintenance cost will not increase when secured surveillance is applied.

4 Benefits

Secured cooperative surveillance increases safety through increased confidence in target data displayed to an ATCO controlling ER or TMA air traffic.

The secured cooperative surveillance allows for use of ADS-B as independent surveillance layer which enables reduction of the number of Mode-S radars. Since ADS-B is a high performance, low cost technology, the ANSP technology cost can be reduced.

The resulting benefit CEF3 in consequence results from cost savings when applying the secured cooperative surveillance together with rationalisation of Mode-S radar infrastructure instead of maintaining the full SSR network as surveillance sensor to support ER and TMA air traffic control.

The Performance Framework [11] 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. In case of the secured surveillance the main benefit results from lower deployment cost. But with it the operating cost are also lower than with a traditional SSR + legacy ADS-B.

The only involved stakeholder, investing, deploying, operating and benefitting secure ADS-B, are ANSPs who introduce it.

Performance Framework KPA[3]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year 2033	Year 2040	Year 2043
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	G2G ANS cost changes related to technology and equipment	€/year	NPV: 2.44 M€ Cum NPV 23.19 M€	NPV: 0.76 M€ Cum NPV 31.12 M€	NPV: 0.6 M€ Cum NPV 33.07 M€
	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

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

Performance Framework KPA[3]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year 2033	Year 2040	Year 2043
		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
	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

Performance Framework KPA[3]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year 2033	Year 2040	Year 2043
		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
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**	Kg fuel per movement	Fuel Costs	€/year	N/A	N/A	N/A

Performance Framework KPA[3]	Focus Area	KPI/PI from the Performance Framework	Unit	Metric for the CBA	Unit	Year 2033	Year 2040	Year 2043
		Average fuel burn per flight						
	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 4-1: Results of the benefits monetisation per KPA

5 Cost assessment

5.1 ANSPs costs

5.1.1 ANSPs cost approach

Cost in CBAT is considered as full system cost consisting of the following categories.

The considered cost categories are:

- HW
- Siting / configuration
- Training
- Operating cost
    - Direct
        - Maintenance
    - Non-direct
        - Power
        - Lease-line / Network
        - Licensing

Following cost composition is considered:

- Total NRC: HW + installation
- Operating cost: considered as percentage of Non-Recurring Cost (NRC): covering indirect and direct operating cost and called 'Maintenance cost' in CBA
- For Secured surveillance resulting in a reduction of SSR the resulting total operating cost percentage of NRC is presumably lower than for SSR + legacy ADS-B due to lower maintenance cost, lower power consumption etc.
- The same percentage of NRC for the total operating cost is assumed for both, reference and solution scenario, to be conservative.
- *Environmental footprint: Qualitatively it can be stated that:*
    - *Lower power consumption which is furthermore decreased since less heat is produced and less air conditioning is required,*
    - *No monetary assessment for the environmental impact will be conducted*

The cost figures were established based on expert judgement with representatives from involved stakeholders (manufacturers and ANSP).

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5.1.2 ANSPs cost assumptions

Costs for investment were collected based on knowledge and experience.

Since the solution is applicable to ER and TMA with focus on high density airspace, a split of the number of stations is performed: 30% TMA and 70% ER. The presently assumed split is somewhat arbitrary and this split can vary, since the solution can be applied to different airspace, down to airport.

5.1.3 Number of investment instances (units)

Airport				Terminal Airspace				En-route			
HC	HS	LC	LS	VH	H	M	L	VH	H	M	L
-	-	-	-	210	210	-	-	490	490	-	-

Table 5-1: Number of investment instances - ANSPs

5.1.4 Cost per unit

For detailed cost composition see CBAT-model provided in Sect. 6

A cost per unit figure is difficult to establish for a mixed equipment scenario. However, in order to allow for a simplified comparison an average cost figure per unit was established just for comparison reasons.

The cost per unit for reference scenario (SSR + legacy ADS-B) is determined by combining the cost figures for SSR and legacy ADS-B for total number of systems, divided by number of ADS-B units in reference scenario

Cost category	Airport				Terminal Airspace				En-route			
	HC	HS	LC	LS	VH	H	M	L	VH	H	M	L
Pre-Implementation Costs + Implementation costs	-	-	-	-	0.407 M€	0.407 M€	-	-	0.407 M€	0.407 M€	-	-
Operating costs	-	-	-	-	0.0285 M€	0.0285 M€	-	-	0.0285 M€	0.0285 M€	-	-

Table 5-2: Cost per Unit reference scenario – ANSP

Cost per unit for solution scenario is determined following the same approach as for the reference scenario, but using the cost figures for the solution scenario.

Cost category	Airport				Terminal Airspace				En-route			
	HC	HS	LC	LS	VH	H	M	L	VH	H	M	L
Pre-Implementation Costs + Implementation costs	-	-	-	-	0.351 M€	0.351 M€	-	-	0.351 M€	0.351 M€	-	-
Operating costs	-	-	-	-	0.0246 M€	0.0246 M€	-	-	0.0246 M€	0.0246 M€	-	-

Table 5-3: Cost per Unit solution scenario – ANSP

5.1.5 Total overall cost

Using the approach given above to obtain a comparison number, a total cost figure (pre-implementation + operating, multiplied by number of units) can be established. But this approach will lack the effect from avoided cost (avoided CAPEX and avoided OPEX) in the CBAT model. Especially if a comparison over the years is of interest, the cost through saved expenditures have to be taken into account.

For comparison of the total ADS-B cost the figures from the CBAT model for reference as well as for solution scenario are shown in table 5-4. These are provided to summarise the total overall cost for reference and solution scenario for year N (2033), N+X (2040), N+Y (2043). The figures do not contain the negative cost from Mode-S rationalization and also do not contain the decommissioning cost.

The total cost including the Mode-S rationalization is shown in table 5-5.

	2033	2040	2043
Ref. Total (cumulative) cost of new HW Pre-ops	12.150.000,00 €	12.150.000,00 €	12.150.000,00 €
Ref. Total ADS-B Maintenance / Operational cost	12.505.500,00 €	12.600.000,00 €	12.600.000,00 €
Ref. Total Cost	24.655.500,00 €	24.750.000,00 €	24.750.000,00 €
Sol. Total (cumulative) cost of new HW Pre-ops	33.712.500,00 €	33.712.500,00 €	33.712.500,00 €
Sol. Total ADS-B Maintenance / Operational cost	12.978.000,00 €	13.125.000,00 €	13.125.000,00 €
Sol. Total Cost	46.690.500,00 €	46.837.500,00 €	46.837.500,00 €

Table 5-4: Total Cost for ADS-B (w/o Mode-S rationalisation) for reference and solution scenario for years 2033, 2040 and 2043 – ANSP

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Ref Scenario:	2033	2040	2043
Ref. Total cost	-540.700,00 €	-9.079.000,00 €	-9.079.000,00 €
Sol. Total cost	-5.060.875,00 €	-11.480.000,00 €	-11.480.000,00 €

Table 5-5: Total Cost for reference and solution scenario for years 2033, 2040 and 2043 – ANSP

Due to the avoided CAPEX and OPEX the figures become negative – they turn into savings. The difference is how much is saved in reference and in solution scenario. And there it shows that the solution scenario provides lower cost compared to the reference scenario, even with the conservative assumptions considered in this CBAT.

5.2 Airport operators costs

There are no associated costs of the solution

5.2.1 Airport operators cost approach

There are no associated costs of the solution

5.2.2 Airport operators cost assumptions

There are no associated costs of the solution

5.2.3 Number of investment instances (units)

There are no associated costs of the solution

5.2.4 Cost per unit

There are no associated costs of the solution

5.3 Network Manager costs

There are no associated costs of the solution

5.3.1 Network Manager cost approach

There are no associated costs of the solution

5.3.2 Network Manager cost assumptions

There are no associated costs of the solution

5.3.3 Network Manager cost figures

There are no associated costs of the solution

5.4 Airspace User costs

There are no associated costs of the solution

5.4.1 Airspace User cost approach

There are no associated costs of the solution

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5.4.2 Airspace User cost assumptions

There are no associated costs of the solution

5.4.3 Number of investment instances (units)

There are no associated costs of the solution

5.4.4 Cost per unit

There are no associated costs of the solution

5.5 Military costs

There are no associated costs of the solution

5.5.1 Military cost approach

There are no associated costs of the solution

5.5.2 Military cost assumptions

There are no associated costs of the solution

5.5.3 Number of investment instances (units)

There are no associated costs of the solution

5.5.4 Cost per unit

There are no associated costs of the solution

5.6 Other relevant stakeholders

There are no associated costs of the solution

6 CBA Model

For the PJ14-W2-84c 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. The model followed the approach, methodology and some assumptions for ad-hoc CBAT model taken by solution PJ14-W2-84d [12].

CBAT Model
D12.3.500-PJ14-W2-

7 CBA Results

Table 7-1: Result table from Excel Model

Value	Unit	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
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	2,36	2,36	2,36	2,36	2,36	2,36	2,36	2,36	2,36	2,35	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
OPEX PV	MEUR	0,24	0,48	0,72	0,96	1,20	1,44	1,68	1,92	2,16	2,40	2,40	2,40	2,40	2,40	2,40	2,40	2,40	2,40	2,40
CAPEX NPV	MEUR	2,36	2,18	2,02	1,87	1,73	1,61	1,49	1,38	1,27	1,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
OPEX NPV	MEUR	0,24	0,44	0,62	0,76	0,88	0,98	1,06	1,12	1,17	1,20	1,11	1,03	0,95	0,88	0,82	0,76	0,70	0,65	0,60
PV	MEUR	2,60	2,84	3,08	3,32	3,56	3,80	4,04	4,28	4,52	4,75	2,40	2,40	2,40	2,40	2,40	2,40	2,40	2,40	2,40
NPV	MEUR	2,60	2,63	2,64	2,64	2,62	2,59	2,55	2,50	2,44	2,38	1,11	1,03	0,95	0,88	0,82	0,76	0,70	0,65	0,60
Cumulative PV	MEUR	2,60	5,44	8,52	11,84	15,40	19,20	23,24	27,52	32,04	36,79	39,19	41,59	43,99	46,39	48,79	51,19	53,59	56,00	58,40
Cumulative NPV	MEUR	2,60	5,23	7,87	10,50	13,12	15,71	18,25	20,75	23,19	25,57	26,68	27,71	28,66	29,55	30,36	31,12	31,82	32,47	33,07

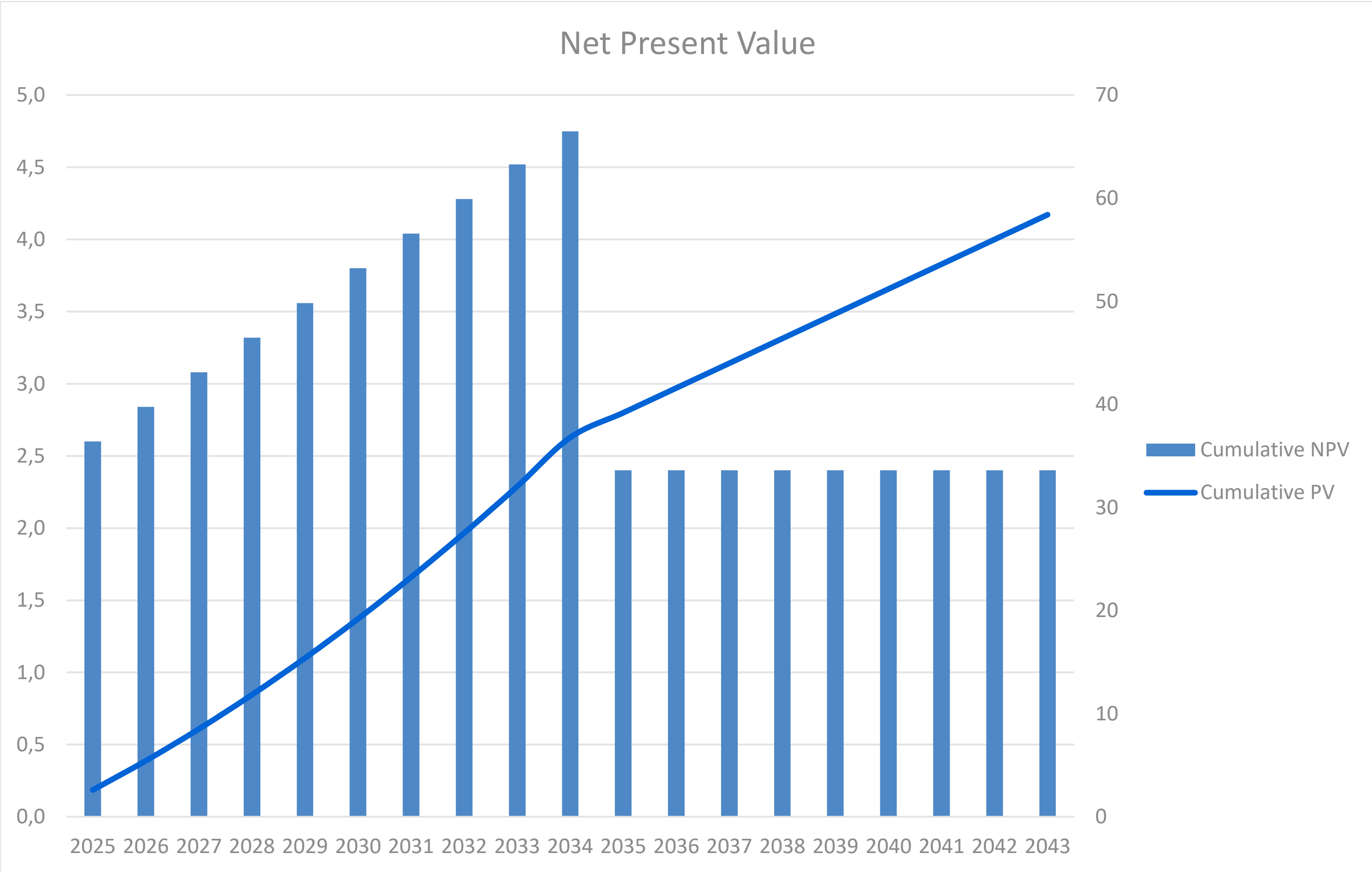

Figure 7-1: Present Value (M€) over years

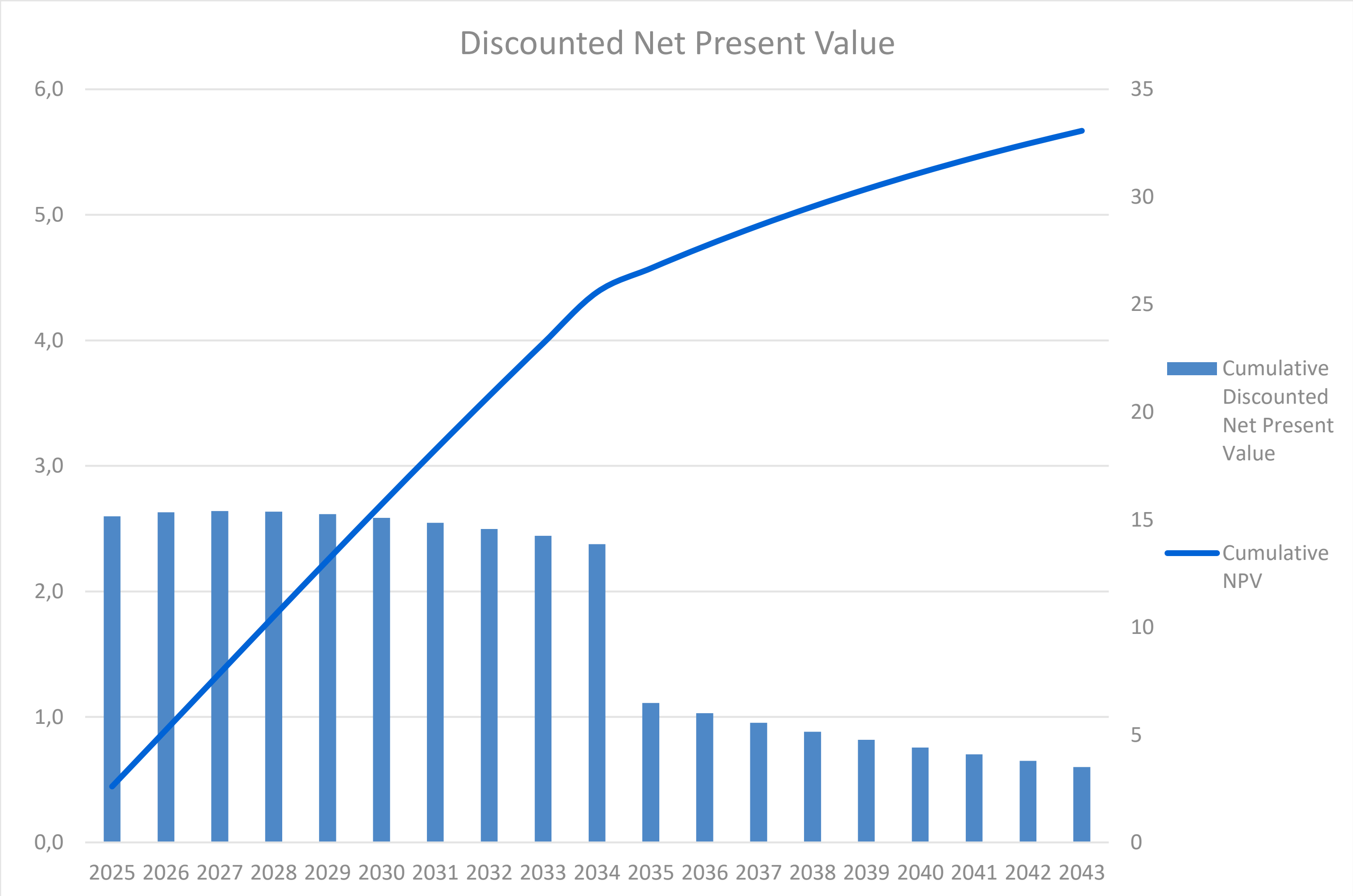

Figure 7-2Net Present Value (M€) over years

The figures 7-1 and 7-2 respectively show the resulting Net Present Value and Discounted Net Present value over the assessment period. Per figure the per year as well as the cumulated NPV / Discounted NPV is shown.

The figures show clearly the positive result due increased cost efficiency of the solution scenario compared to the reference scenario.

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8 Sensitivity and risk analysis

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 secured ADS-B stations.
- 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 secured ADS-B stations compared to the cost of legacy ADS-B stations.
- 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 following graph is extracted from the CBAT model and depicts the impact of the Discount rate on the NPV:

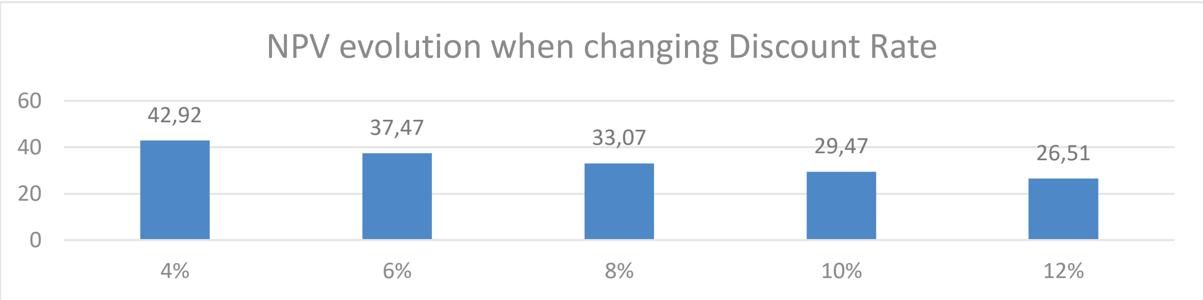
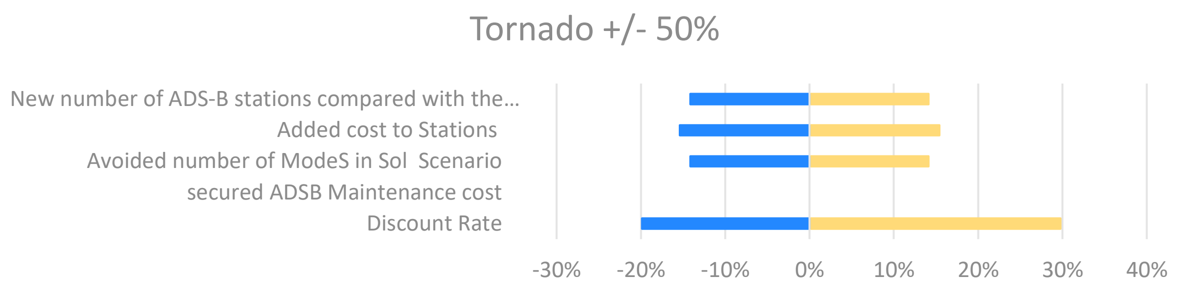
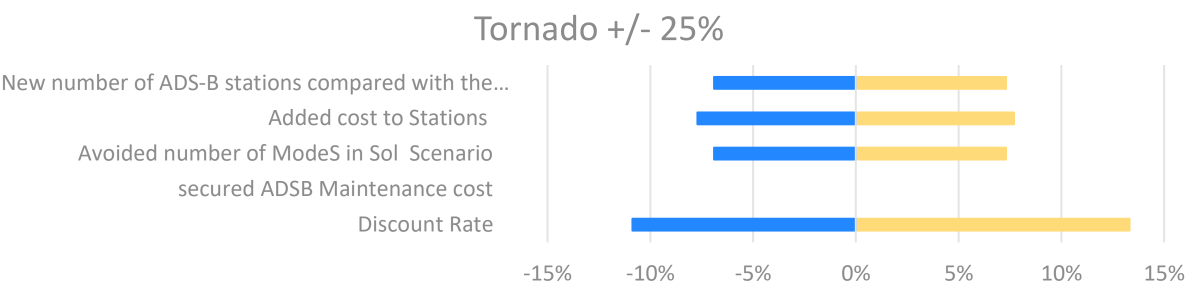


Figure 8-1: NPV variation (M€) for different discount rates in percent With increasing discount rate the NPV will decrease.



	Discount Rate	secured ADSB 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%	-20%	0%	-14%	-15%	-14%
-50%	30%	0%	14%	15%	14%

Figure 8-2: Tornado graph +/- 50%



	Discount Rate	secured ADSB 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%	-11%	0%	-7%	-8%	-7%
-25%	13%	0%	7%	8%	7%

Figure 8-3: Tornado graph +/- 25%

9 Recommendations and next steps

The present CBA was established from the perspective of a technological solution. It compares the cost of ER and TMA secured surveillance ADS-B sensor implementations against a reference scenario applying legacy ADS-B surveillance sensors.

It is important to note that although the approach used in the CBAT is similar to the one applied in Solution 84d, the two solutions are different, although complementary.

While Solution 84d aims to validate the Phase Overlay technology, Solution 84c studies threats and develops and validates preventive measures against possible ADS-B attacks. The benefits of Phase Overlay include an increase of available data in each ADS-B message, which can be used for different purposes (security among them) and which leads to the possibility of a reduction of spectrum congestion as well as additional information for controllers.

The security functionality developed by Solution 84c aims to independently validate information provided by the airborne segment and received in the ground segment for use in air traffic control. This increases the confidence in the received data (increase in integrity) and is seen to provide a prerequisite for the use of ADS-B as independent surveillance layer in high density airspace. In this regard it is expected, that the functionality developed and validated by Solution 84c will be an important function in addition to an encrypted and authenticated message transmission.

Apart from being different, none of the two solutions is linked to an operational solution, therefore the profitability of the CBA is based on assumptions related to the actual benefits. In this case, both solutions have focused their assumptions on obtaining monetary benefits through the rationalisation of the current infrastructure in favour of increased use of ADS-B surveillance, which is a logical consequence when using ADS-B as independent surveillance layer. However, there are differences in the way they achieve this profit. Both solutions complement each other, with one pursuing the security of the message transmission (Solution 84d), and the other by increasing security through validation of the message content in the ground segment (Solution 84c).

With these differences the implementation should be assessed independently and according to local needs. However, in general it is recommendable to envisage the implementation of both solutions because different aspects would be resolved: spectral congestion with 84d and data integrity with 84c.

The resulting benefit of solution PJ.14-W2-84c is cost saving resulting from applying secured surveillance compared to state-of-the-art existing technology, i.e. SSR + legacy ADS-B. The assessment is conservative, it assumes a SUR infrastructure rationalisation (removal of Mode A/C SSR and reduction of Mode-S SSR in reference and solution scenarios. The difference is that secured ADS-B allows for a stronger reduction of Mode-S SSR's. The assumed number of additionally rationalised Mode-S SSR's with secured ADS-B is very conservative.

Based on the performed analysis cost-savings would result by applying the solution scenario compared to the reference scenario. This holds also true if influencing factors (discount rate, cost per unit estimate, number of units) vary. The cost savings would increase if a stronger rationalisation of Mode-S SSR's would be pursued.

In consequence the recommendation is to consider the secured surveillance as surveillance sensor instead of the legacy ADS-B.

10 References and Applicable Documents

10.1 Applicable Documents

[1] SESAR Project Handbook; SJU, ed. 02.02.00, June 2020

[2] Guidelines for Producing Benefit and Impact Mechanisms; EUROCONTROL, ed. 03.00.01, October 2014

[3] Methods to Assess Costs and Monetise Benefits, EUROCONTROL, ed. 00.02.02, October 2014

[4] SESAR Cost-Benefit Analysis Model[4], s7.3.8, February 22

[5] Standard Inputs for Cost-Benefit Analyses, EUROCONTROL, ed. 8.0, January 2018

[6] ATM CBA Quality checklist, SESAR2020 PJ19.04, ed. 5.1, May 2020

[7] Methods to Assess Costs and Benefits for CBAs, SESAR2020 PJ19.04, May 2020

10.2 Reference Documents

[8] Common assumptions

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

[10] Performance Framework

[11] Airport OE_December 2017 Version (1.0)

[12] CBAT Model solution PJ14-W2-84d, SESAR2020 PJ.14-W2-84c, ed. 00.01.02, September 2022

[13] Automatic dependent surveillance - broadcast, EUROCONTROL: https://www.eurocontrol.int/

[4] This reference is no more accessible from Programme library but it is now available in ATM Performance Assessment Community of Practice.

11 Appendix

Mapping between ATM Master Plan Performance Ambition KPAs and SESAR Performance Framework KPAs, Focus Areas and KPIs, source reference *[10]*

<table>
<tr><th>ATM Master Plan SESAR Performance Ambition KPA</th><th>ATM Master Plan SESAR Performance Ambition KPI</th><th>Performance Framework KPA</th><th>Focus Area</th><th>#KPI / (#PI) / <Design goal></th><th>KPI definition</th></tr>
<tr><td rowspan="2">Cost efficiency</td><td rowspan="2">PA1 - 30-40% reduction in ANS costs per flight</td><td rowspan="2">Cost efficiency</td><td rowspan="2">ANS Cost efficiency</td><td>CEF2</td><td>Flights per ATCO hour on duty</td></tr>
<tr><td>CEF3</td><td>Technology Cost per flight</td></tr>
<tr><td rowspan="6">Capacity</td><td rowspan="2">PA7 - System able to handle 80-100% more traffic</td><td rowspan="5">Capacity</td><td rowspan="2">Airspace capacity</td><td>CAP1</td><td>TMA throughput, in challenging airspace, per unit time</td></tr>
<tr><td>CAP2</td><td>En-route throughput, in challenging airspace, per unit time</td></tr>
<tr><td rowspan="3">PA6 - 5-10% additional flights at congested airports</td><td>Airport capacity</td><td>CAP3</td><td>Peak Runway Throughput (Mixed Mode)</td></tr>
<tr><td rowspan="2">Capacity resilience</td><td><RES1></td><td>% Loss of airport capacity avoided</td></tr>
<tr><td><RES2></td><td>% Loss of airspace capacity avoided</td></tr>
<tr><td>PA4 - 10-30% reduction in departure delays</td><td>Predictability and punctuality</td><td>Departure punctuality</td><td>PUN1</td><td>% of Flights departing (Actual Off-Block Time) within +/- 3 minutes of Scheduled Off-Block Time after accounting for ATM and weather related delay causes</td></tr>
</table>

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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 CO2 emissions			(FEFF2)	CO2 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

[14] **Table 11-1: Mapping between ATM Master Plan Performance Ambition KPAs and SESAR Performance Framework KPAs, Focus Areas and KPIs**

-END OF DOCUMENT-