SESAR 2020 PJ.14-W2-79a: COST BENEFIT ANALYSIS (CBA) FOR V3/TRL6

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PJ.14-W2-79A GAST D EXTENDED SCOPE

This CBAT 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 Cost Benefit Analysis (CBA) document addresses GBAS CAT II/III L1 approach and landing system as covered by the SESAR 2020 technological solution PJ.14-W2-79a GAST D Extended Scope. The GAST D Extended Scope deals with the threat scenarios identified in SESAR 1 15.03.06 related to operation under adverse atmosphere conditions typically occurring in non-mid latitude areas and GAST D ground station operation when subject to unintentional RFI in airport environments.

Extensive Cost Benefit Analysis work has already been developed covering the GAST D solution in SESAR 1 and wave 1. In wave 2, PJ.14-W2-79a has reviewed the existing CBA related documentation with the aim to verify the applicability of the existing CBA considering PJ.14-W279a GAST D Extended Scope and to update cost estimates that are provided in:

- SESAR 1 15.03.06 D25 GBAS CAT II/III L1 Cost Assessment Report
- SESAR Deployment Manager (SDM) GBAS Business Case, Release 1, 2020

Monetization of benefits was carried out in SESAR Deployment Management CBA and is considered valid also the solution scenario defined for PJ14-W2-79a. A revised cost assessment has been carried out taking into consideration acquired knowledge and changes in equipment and maintenance cost level since the previous CBAs were written.

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1 Executive Summary

This document is the Cost Benefit Analysis (CBA) produced by the technological solution PJ.14-W2-79a GAST D Extended Scope. The GAST D technological solution for nominal operational conditions was validated to TRL6 level in SESAR 1 15.03.06. In SESAR 2020 wave 2, the GAST D Extended Scope technological solution deals with validating GAST D performance when subject to two *abnormal* operational conditions: severe ionospheric gradient and scintillation conditions and unintentional RFI threats occurring in the airport environment. The target maturity level at end of wave 2 for the two technical enablers covering these aspects is TRL6, thus closing two threat scenarios identified in SESAR 1. Within wave 1 and wave 2 GAST D Extended scope, VDB measurement equipment from SESAR 1 is further enhanced; a runway coverage simulation tool, and a horizontally polarized VDB measurement antenna that fits on a measurement van have been developed. These tools are used to validate ICAO Doc. 8071 Vol. II requirements. Such tools provide a means to show compliance to regulatory requirements and facilitate cost efficient deployment and maintenance of a GBAS system at the airport.

The CBA builds upon previously published GBAS Cost Benefits Analysis; SESAR 1 15.03.06 D25 GBAS CAT II/III L1 Cost Assessment Report, Ed. 00.02.00, September 2015, D51 SESAR 1 Business Case – Consolidated Deliverable with contributions from 16.06.01-16.06.02-16.06.03-16.06.05 July 2016, SESAR 2020 PJ20 D2.6 Consolidated Business Case (2018) and (2019), and SESAR Deployment Manager GBAS Business Case, Release 1, 2020.

The benefits of deploying GAST D as next generation precision approach system replacing current ILS CAT II/III in Europe is revisited (elaborated in SESAR Deployment Manager (SDM) GBAS Business Case). The SDM CBA scenarios dealt with large and complex airports operating under nominal conditions in Central Europe. In this CBA, factors related to the adverse operating environment conditions addressed by the PJ.14-W2-79a that can impact local CBAs when deploying GAST D in Equatorial and Nordic regions are discussed.

In the original CBA report by SESAR 1 15.03.06, the cost estimates were provided by the ANSPs, the GBAS ground station manufacturers and the aircraft manufacturers members of 15.03.06 project. Revision and refinement of the cost items are provided by the SESAR 2020 PJ.14-W2-79a GAST D Extended Scope solution partners represented by ANSPs, Ground Station manufacturer, and research institutes. As no GBAS airborne receiver manufacturers are participating in the wave 2 PJ.14-W2-79a solution, this report does not include any re-assessment or additional data related to airborne receiver cost.

The SESAR 1 ground segment cost figures covering the GBAS ground station procurement and the related installation, commissioning, Operation and Maintenance have been reviewed. Costs for the preparation and publication of a GBAS approach procedure have been reviewed as well. This CBA follows the approach taken by the SESAR 1 GBAS CBA D25, namely that the assessment supports a high level GBAS business case, not related to a specific installation site for the ground system. It has been chosen to provide cost figures for a generic scenario: this necessarily limits the accuracy of the estimations (the complexity of the area where to deploy the GBAS approach system strongly affects the costs) but provides insight in the cost base of a GBAS ground system.

All the quantified costs appearing in this report must be considered as approximate, ROM estimations, and they do not constitute any form of commitment of the companies providing the data.

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2 Introduction

2.1 Purpose of the document

This document addresses the Cost Benefit Analysis (CBA) of the GBAS CAT II/III L1 approach and landing system. It clarifies how the SESAR 2020 PJ.14-W2-79a GAST D Extended Scope work items impact the published SESAR 1 and SESAR Deployment Manager CBAs [9][10] for GAST D. PJ14-W2-79a has as objective to develop and validate an Ionosphere Gradient Monitor (IGM) to ensure GAST D integrity under adverse ionosphere conditions. In addition, the solution addresses unintentional RFI impact on GBAS Ground Station performance. These aspects are considered to form part of a standard GBAS GAST D ground station, and the target for PJ14-W2-79a has been to validate that the built-in mitigations can cope with these environmental conditions.

All the quantified costs appearing in this report must be considered as approximate, Rough Order of Magnitude (ROM) estimations. The provision of such figures does not constitute, for any of the task members, a commitment to provide the described product and/or services at the indicted cost, nor to provide the mentioned product and/or services themselves.

Estimated costs are given in Euro (€). Hourly rates, conversion data, and input data supporting the cost assessment are based on the [17] provided by SESAR PJ19 transversal team.

2.2 Scope

The scope of the CBA is to review the existing GBAS CAT II/III L1 CBAs taking into consideration acquired knowledge and possible changes in equipment and maintenance cost level since the previous CBAs were written. Update of existing cost estimates and identification of new cost items is carried out. Also, the CBA activity includes identifying and assessing any change in the CBA resulting from the validation activities carried out within the wave 2 GAST D Extended Scope.

The scope of the CBA update reflects the scope of the project related to GBAS in SESAR 2020 in the sense that it considers the impact of the activities that have taken place in the project.

Benefit analysis is limited to qualitative analysis. As in the SESAR 1 CBA, monetization of the benefits is not carried out. The impact that PJ14-W2-79a GAST D Extended Scope tasks have on SESAR KPIs is discussed regarding the effect on local CBAs for GAST D operating at airports located in non-mid latitude European areas.

2.3 Intended readership

The intended audience of this document is SESAR Joint Undertaking and PJ14-W2-79 partners.

The document may interest ANSPs, Airport operators, and other stakeholders that consider acquisition and deployment of a GAST D system.

2.4 Structure of the document

This document follows the structure of CBA template present in the SESAR2020 programme library for the enabling solution projects. Paragraphs and Appendices not applicable to the proposed technological solution are indicated as "Not Applicable".

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

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Section 1: Executive Summary.

Section 2: This section introduces the document.

Section 3: Provides the objectives and scope of the CBA.

Section 4: Presents the benefits.

Section 5: Provides the cost assessment for the procurement, deployment, and O&M of a generic GAST D system.

Section 6: According to the template this section presents the CBA model. In this CBA, no model is developed. The scope is limited to reviewing and discussing existing CBA from SESAR 1 and wave 1.

Section 7: Summarizes the CBA work.

Section 8: According to the template this section provides a sensitivity and risk analysis. Such an analysis is not carried out in this CBA.

Section 9: Provides recommendations for further consideration.

Section 10: Lists the relevant references used within the document.

Appendix 11: Discusses the three subtasks of PJ.14-W2-79a solution in light of impact on CBA (either benefit or cost assessment).

Appendix 12: Cost item estimates from SESAR 1 D25 are presented in a table for reader's convenience.
Appendix 13: Cost item estimates from SESAR Deployment Management GBAS CBA are presented in a table for reader's convenience. The monetized benefits are not repeated here, and the reader is referred to SDM GBAS CBA [10] for the details.

2.5 Background

This document complements existing Cost Benefit Analysis (CBA) for the GAST D solution, specifically addressing topics related to PJ.14-W2-79a GAST D Extended Scope. The CBA builds upon two previously published GBAS Cost Benefits Analysis related documents:

1. SESAR 1 15.03.06 D25 GBAS CAT II/III L1 Cost Assessment Report, Ed. 00.02.00, September 2015 [9]
2. SESAR Deployment Manager GBAS Business Case, Release 1, 2020 [9]

In SESAR 1, the project 16.06.06 produced the deliverable D51 SESAR 1 Business Case – Consolidated Deliverable with contributions from 16.06.01-16.06.02-16.06.03-16.06.05 [11] covering 10 SESAR 1 solutions. One of the solutions was solution #55 Precision Approaches using GBAS CAT II/III based on GPS L1 (LVP using GBAS). In SESAR 2020 the transversal project PJ20 sWP2.6 in SESAR wave 1 produced the deliverable SESAR 2020 PJ20 Consolidated Business Case (2018) and (2019) [12] summarizing the sWP2.6 business case activities carried out in support of the development of Common Project 2 proposal and support to the Master Plan Campaign. The deliverables [11] and [12] have been superseded by the SDM GBAS Business Case and will therefore not be reviewed as separate business case, though they have been used as background material.

The GBAS CAT II/III L1 system technological solution (GAST D) operating in nominal conditions was validated to TRL6 in SESAR 1. A conclusion from SESAR 1 15.03.06 project was that GAST D operation under specific adverse conditions required additional validation. These adverse conditions have been the focus of SESAR 2020 wave 1 and wave 2 technological solutions PJ.14-03-01 and PJ.14-W2-79a GAST D Extended Scope, targeting TRL4 and TRL6, respectively. The abnormal operating conditions are:

- Severe ionosphere gradient and scintillation occurrences
- Unintentional Radio Frequency Interference occurrences.

In SESAR 2020, real life data has been collected to allow characterization and modelling of the threat sources. Monitoring and detection algorithms have been developed and validated against ICAO performance requirements.

During SESAR 1 it was also found that VDB coverage, especially for large and complex airports, could be challenging. Consequently, activities were identified for SESAR 2020, focusing on measurement equipment and simulations. In wave 1, the VDB measurement equipment from SESAR 1 was enhanced with more advanced functionality and a runway coverage simulation tool was developed to provide a feasible means to verify that the VDB field coverage conforms with ICAO Annex 10 Vol. I requirements. In wave 2, a horizontally polarized VDB measurement antenna located on the roof of a van is developed and will be used together with the VDB measurement equipment to technically verify ICAO Doc 8071 Vol. II ±3 dB measurement uncertainty requirement. The main objective of this work is to improve the accuracy of the VDB field measurements.

In the SESAR 1 cost assessment, the provided cost item estimates were worked out by GBAS ground station manufacturers, aircraft manufacturers and ANSP's. The costs were estimated from the investor perspective; the costs related to the system acquisition for airspace users, ANSP's or airports.

The SESAR 1 cost assessment developed by 15.03.06 considered the cost of implementing GBAS on an airport but it did not consider any potential cost savings related to reduction in ILS infrastructure as the deliverable did not address benefits.

The SESAR Deployment Manager CBA lists the expected benefits, estimated GBAS deployment cost per system, as well as derived cost estimates related to implementing GBAS CAT II/III on a scope of 16 airports with Low Visibility Conditions in two different (rapid and prolonged) GBAS deployment scenarios (replacing ILS as main navigation system).

2.6 Glossary of terms

Term	Definition	Source of the definition
Ionospheric Anomalies	Small scale structures in the ionosphere can result in non-differentially corrected errors in the GBAS position. Such phenomena are typically associated with solar storm activity and may be characterized by steep gradients in the ionospheric delay over a relatively short distance (e.g., a few tens of kilometres). The errors that may be induced by these phenomena result when the airborne receiver and ground subsystem are	ICAO Annex 10 Vol 1: D.7.5.6.1 Ionospheric Anomalies.

	receiving satellite signals that have different propagation delays. Also, since GBAS uses code-carrier smoothing with a relatively long time constant, biases build up in these filters that are a function of the rate of change of ionospheric delay. If the ground subsystem and airborne receivers experience significantly different delays and rates of change of the ionospheric delays, the biases that build up in these filters will not match and will not be cancelled by the differential processing.	
Net Present Value	Net Present Value (NPV) is the sum of all discounted cash inflows and outflows during the time horizon period.	Investopedia
KPA	A way of categorising performance subjects related to high level ambitions and expectations. ICAO Global ATM Concept sets out these expectations in general terms for each of the 11 ICAO defined KPAs.	SESAR Performance Framework ed 01.00.01, 2019
KPI	Key PI is a performance indicator that is associated with a SESAR Validation Target.	SESAR Performance Framework ed 01.00.01, 2019
OI	Operational Improvement for ATM solution	
PI	Performance Indicators are indicators that help either the calculation of KPIs or the expression of a solution's impact. PI's may be solution specific.	SESAR Performance Framework ed 01.00.01, 2019
POI	Preparatory Operational Improvement (Operational Improvement for Technological Solutions)	
Scintillation	Scintillation is caused by ionospheric irregularities, which affect the GNSS signal through refraction and diffraction. The presence of scintillation is a key difference between the high and low magnetic latitudes and the mid-latitudes. Scintillation is typically more severe in the low magnetic latitudes, and the consequence is that affected GNSS ranging source signals become substantially noisier. Scintillation affects	D9.1.400 PJ.14-W2-79a TVALR

	continuity and availability directly, while integrity is less affected since it does not create a differential error.	

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
ACC	Area Control Centre
ANSP	Air Navigation Service Provider
APP	Approach
APV	Approach with Vertical guidance
ATM	Air Traffic Management
CAT	Category
CBA	Cost Benefit Analysis
DMC	Terminal Manoeuvring Area
EIS	Entry Into Service
EOC	Essential Operational Changes
GAST	GBAS Approach Service Type
GBAS	Ground Based Augmentation System
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning Service
GS	Glide Slope
GS	Ground Stations
HC	High complexity (airport)
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IRE	Instrument Runway End
KPA	Key Performance Area
KPI	Key Performance Indicator
LC	Low complexity (airport)

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LVC	Low Visibility Conditions
MMR	Multi-Mode Receiver
NPV	Net Present Value
NRC	Non-Recurring Cost
O&M	Operation and Maintenance
OI	Operational Improvement
PAR	Performance Assessment Report
PI	Performance Indicator
PIRM	Programme Information Reference Model
PAR	Performance Assessment Report
POI	Preparatory Operational Improvement
RC	Recurring Cost
ROI	Return On Investment
ROM	Rough Order of Magnitude
RTCA	Radio Technical Commission for Aeronautics
SARPs	(ICAO) Standards and Recommenced Practices
SESAR	Single European Sky ATM Research Programme
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
TMA	Terminal Manoeuvring Area
VDB	VHF Data Broadcast
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions

Table 2: List of acronyms

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3 Objectives and scope of the CBA

3.1 Problem addressed by the solution

The fundamental functions of the GBAS Ground Station (GS) are to calculate differential corrections from the received GNSS (here GPS L1) satellite signals to provide an integrity function and to broadcast this information to recipient aircraft. The GBAS aircraft receiver utilizes the corrections in its computation of the precise position of the aircraft. Using this precise position together with Final Approach Segment information broadcast from the GBAS GS, the GBAS avionics system can provide precision approach guidance under poor visibility conditions.

GBAS approach services are differentiated into several types, namely GBAS Approach Service Types (GAST). GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert to provide approach guidance with quantifiable performance. GAST A, B, and C are intended to support typical APV I, APV II, and Category I operations, respectively. GAST D has been introduced to support landing operations in lower visibility conditions including CAT III operations. A GAST D ground subsystem also provides the approach service type C. The reader is referred to SESAR 1 D25 CBA [9] for a more elaborate description of the GBAS concept.

GBAS is intended to provide guidance to support all types of approach, landing, rollout, and take-off within its service volume. In PJ.14-W2-79a, primarily approach and landing phase are considered.

The SESAR 1 GBAS activities validated the GAST D operating in nominal conditions to TRL6. Several abnormal conditions relevant to CAT III approach and guided take-off in LVC operations supported by GAST-D were identified in SESAR 1 as requiring further work and are the focus area for PJ.14-W2-79a GAST D Extended Scope:

- Severe Ionospheric gradient and scintillation disturbances
- Unintentional Radio Frequency Interference.
  (Note: The Intentional interference aspect is a security threat which is not addressed by a safety assessment)

The GAST D extended scope solution considers GBAS operating in geographical regions that can encounter severe ionospheric conditions. The derivation of efficient mitigation strategies requires the study of the characteristics of the ionospheric (plasma bubbles, ionospheric gradients, and amplitude and phase scintillation) and tropospheric anomalies. A technical enabler for this scenario was introduced in wave 1 [12]:

- CTE-N07e - "GBAS CAT II/III based on Single-Constellation / Single-Frequency GNSS (GPS L1) extension to equatorial and Nordic regions".

The GBAS system (both SC/SF and MC/DF solution) operating in large and complex airport environments faces both technical challenges such as multipath from obstacles on or around the airport and RFI (unintentional and intentional, in particular jamming and spoofing) threats from a variety of sources, as well as infrastructure and O&M cost/complexity issues that can slow down widespread deployment. Solving GBAS GS siting issues in complex airport (due to either natural and man-made obstacles) and seeking mitigation solutions to undesired interference are a few key factors that are essential for GBAS to meet the requirements of a globally deployable system. A second technical enabler for such complex environments thus introduced in wave 1 [12]:

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- CTE-N07f - "GBAS robustness towards interference".

Within T3.2 "VDB Measurement Equipment" a new VDB measurement antenna was developed with focus to improve work safety (e.g., simple installation of the antenna on the vehicle) and measurement accuracy (verify the ICAO requirement regarding the + /- 3dB measurement accuracy).

3.2 SESAR Solution description

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-W2-79a GAST D Extended Scope	AO-0505-A Improve Low Visibility Operation using GBAS Cat II/III based on GPS L1	OI step definition	Partial (focus on severe iono conditions and RFI threats)	D9.1.110 TS/IRS

Table 3: SESAR Solution PJ.14-W2-79a Scope and related OI steps

OI Steps ref.	Enabler[1] ref.	Enabler definition	Enabler coverage	Applicable stakeholder	Source reference
POI-0026-NAV GAST D Applicability to Equatorial and Nordic regions	CTE-N07e	GBAS CAT II/III based on Single-Constellation / Single-Frequency GNSS (GPS L1) extension to equatorial and Nordic regions	Fully	GBAS GS Manufacturer, ANSP, Airport operator	D9.1.110 TS/IRS
POI-0025-NAV GBAS Applicability to challenging operational	CTE-N07f	GBAS robustness towards interference	Fully	GBAS GS Manufacturer, ANSP, Airport operator	D9.1.110 TS/IRS

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

environments in LVC					

Table 4: OI steps and related Enablers

3.3 Objectives of the CBA

Extensive Cost Benefit Analysis work has already been developed covering the GAST D solution. The objective of the CBA work in PJ.14-W2-79a is to review the existing CBA related documentation to verify, update, and/or further detail the stated cost item values that are provided in:

- SESAR 1 15.03.06 D25 GBAS CAT II/III L1 Cost Assessment Report
- SESAR Deployment Manager GBAS Business Case, Release 1, 2020

Also, the above CBA documents shall be reviewed considering the PJ.14-W2-79a GAST D Extended Scope activities to identify if any new additional cost elements should be introduced.

The review that is carried out in this CBA does not include the cost estimates for the airborne equipment as PJ.14-W2-79a does not have participation from an aircraft manufacturer. The scope of PJ.14-W2-79a is GAST D ground system.

Research and Development costs related to the GAST D technological solution (such as SESAR R&D costs) and ground station manufacturers R&D costs are not included in the cost picture. The CBA cost assessment focuses on deployment, i.e., what the stakeholders will pay to acquire and put the technical GBAS system in place, as well as operate and maintain the system.

The objective of the benefits section is to summarize the benefits provided by the GAST D technology relative to ILS CAT III. The PJ14-W2-79a GAST D Extended Scope tasks are simply closing threat gaps identified in SESAR 1 for the core GAST D solution (achieving TRL6). The qualitative benefits identified for core GAST D solution are not changed when operating in non-mid latitude areas. A qualitative (not quantitative) benefit analysis is carried out. The benefits are not monetarized. Monetization of benefits was carried out in SESAR Deployment Management CBA and is considered valid also for the solution scenarios defined herein.

Appendix **Error! Reference source not found.** describes in more detail the contributions and impact that solution PJ14-W2-79a has on benefits and cost items.

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3.4 Stakeholders[2] identification

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	Approach and landing ANS, all airport environments (simple, complex)	GAST D operation in nominal and abnormal conditions	Discussion, input, and review of results	Quantitative cost estimates, qualitative benefit descriptions
Airport Operators	Approach and landing ANS, all airport environments (simple, complex)	GAST D operation in nominal and abnormal conditions	Discussion, input, and review of results	Collaboration with ANSP to establish/confirm cost estimates
Research Institute	All airport environments (simple, complex) – ground segment	GAST D operation under ground segment unintentional RFI threat conditions	Discussion, input, and review of results	No quantitative cost contributions as research institute not focussed on commercial or market aspects
GBAS GS Manufacturer	All airport environments (simple, complex) – ground segment	GAST D operation under nominal and abnormal conditions	Discussion, input, and review of results	Quantitative cost estimates, qualitative benefit descriptions
EUROCONTROL		GAST D operation in general	Discussion, input, and review of results	[17] used as reference for cost item input

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.

Airborne Manufacturer	N/A	N/A	Not active in the solution or CBA	No input from airborne side.
Regulatory authorities	N/A	N/A	Not active in the solution or CBA	

Table 5: SESAR Solution PJ.14-W2-79a CBA Stakeholders and impacts

3.5 CBA Scenarios and Assumptions

In this CBA we have chosen the CBA Reference Scenario to be the future without the solution and the Solution Scenario is the future with the solution. ILS CAT I, II, and III is the primary approach and landing system in use today. GBAS is developed as the next generation approach and landing system, providing precision approach in low visibility conditions and enabling operational benefits such as advanced approach procedures. In the CBA solution scenario, the GAST D station with appropriate monitors is meant to replace ILS installations currently deployed at a typical airport operating in such regions.

3.5.1 Reference Scenario

The reference scenario is an airport with ILS CAT III in use:

- Medium, large, and very large airports located in non-mid-latitude European regions with low visibility and abnormal atmosphere conditions. The airports are equipped with ILS CAT III in all runway thresholds. No prior installation of GBAS CAT I in the reference scenario.
- Airport with minimum 2 instrument runway ends and ILS Cat. III operating per each IRE.

ILS CAT III installations:

- ILS ground installation at each runway end supporting CAT III procedures per runway end
- The airport runway marking and lighting for CAT I, II, and or CAT III is available.
- The runway is certified for CAT III operations. This certification allows the runway use for CAT I operations.

3.5.2 Solution Scenario

The solution scenario is based on the scope of the PJ14-W2-79a, namely GAST D operating in geographical regions where adverse atmosphere conditions are more prevalent.

The solution scenario is an airport with GAST D system is deployed

- at medium, large, and very large airports in non-mid-latitude European regions with low visibility and abnormal atmosphere conditions. All runway ends are serviced by the GAST D ground subsystem.

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- An ILS CAT III is kept per runway direction

The solution scenario includes retaining at least one ILS CAT III per runway direction for the following reasons:

- to cater for the fact that the airport will also need to support non-GBAS-capable aircraft.
- there is a need for a back-up to low visibility procedures based on GAST D. It would not be acceptable to deviate the aircraft to the alternate airport in case of a GNSS threat (e.g., constellation outages, jamming, spoofing). A back-up is needed until availability of DFMC GBAS.

The solution scenario takes a high-level generic view of the airport and the site where the GAST D system is to be employed. The are many site-specific considerations that are not possible to generalize in the CBA. The complexity of the area where to deploy the GBAS approach system can strongly affect the costs. The aim of the analysis in section 4 is to identify the solution benefits with respect to the reference scenario and discuss how these factors impact the CBA.

For simplicity, a basic GAST D station is assumed in the analysis, i.e., non-redundant station, four GPS antennas/receivers, one VDB transmitter. Note that a GAST D station can also service GAST C.

3.5.3 Assumptions

The GAST D service is provided in this scenario to all runway ends with sufficient availability by a single ground station.

This assumption is set because in the practice there may be cases where the GAST D service cannot be provided with sufficient availability to remote runway ends.

The reference and solution scenarios include medium size airports. The background for this OE is that many airports located in non-mid latitude regions are medium size. Such airports are candidates for GAST D deployment. It would be unrealistic to exclude them. For the SDM CBA, large and extra-large OE was relevant given that the SDM CBA was to provide input to the Common Projects 2 programme as well as the selected large and very large airports were more natural candidates for the initial GBAS deployment strategy.

The current CBA is focused on low visibility conditions. Therefore, it does not address the fact that a GAST D ground station provides service to both GAST D and GAST C users.

The PJ14-W2-79a subtask T3.1.1 validations show that the GAST D station has the potential to operate safely under ionospheric gradients and that ionospheric disturbances (gradients, plasma bubbles and scintillations) are sufficiently rare and benign that they do not have a significant impact on availability. Based on this, the conclusions and benefit analysis from SDM GBAS CBA are considered valid also for airports in high and low latitude, provided the operational conditions are similar. There is no need for a separate CBA re-doing the SDM CBA for airports located in non-mid latitude regions. Appendix **Error! Reference source not found.** discusses this further.

Variations due to geographical topology, regional ionosphere conditions (see [15]), local operational requirements need to be assessed in local CBAs for the individual airports.

4 Benefits

4.1 Scope

The Benefit section focuses on the benefit of the GAST D technological solution compared with the system that is replacing, namely ILS CAT II/III installations. Note that the benefits provided by Single Frequency Single Constellation GBAS CAT II/III L1 are extensively discussed in the existing CBAs [9][10][11][12].

Operational benefits are not presented in this CBA. The operational benefits are assumed elaborated by the SESAR solution that is implementing the operational improvement.

The SESAR 2020 Performance Framework defines the following KPAs:

- Safety
- Security
- Environment
- Capacity
- Operational Efficiency
- Predictability
- Cost Effectiveness
- Flexibility
- Access and Equity

The GAST D technological solution will impact a number of these KPAs by virtue of the capabilities and properties designed into the GBAS concept and supported by the underlying satellite-based technology. In addition, the GAST D solution is an enabler to operational improvements that contribute to further improve the same KPAs and provide benefits to additional KPAs, as discussed in more detail in the following sections.

In general, ICAO NSP GBAS Working Group (GWG) confirmed during Jwgs/9 June 2022 that it is necessary to implement GBAS GAST D operationally as a step from ILS CAT III to more advanced forms of GBAS CAT III, such as ultimately DFMC GBAS.

The SDM cost benefit assessment [10] provides monetized cost benefit assessment from the reference scenario to GBAS GAST D for a number of airports in Europe. The next step, to arrive at our solution scenario, is to consider differences that are relevant for the non-mid-latitude region. Provided that these airports are similar in size and traffic, the same benefits will apply, as listed below. The potential difference would be reduced availability in case of excessive ionospheric activity in non-mid-latitude regions. Availability considerations are addressed in D9.1.400 PJ.14-W2-79a TRL6 TVALR **Error! Reference source not found.** and further discussed herein in Appendix **Error! Reference source not found.**. The reduced availability could result in reduced benefits if it occurs in the same period of time as CAT III conditions.

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4.2 Benefits provided by GAST D relative to ILS CAT III

Safety KPA

ICAO SARPS define the integrity and continuity performance requirements that GAST D shall meet. These requirements are independent of the operating environment. The fulfilment of these requirements for GAST D solution operating under nominal atmosphere conditions was validated in SESAR1. In SESAR 2020 wave 2, the feasibility of satisfying these performance requirements under abnormal atmosphere conditions using appropriate monitors is validated. Safety as KPI is maintained with respect to the reference ILS CAT III scenario.

Environment KPA

Environmental sustainability:

- Noise reduction and CO2 emissions savings due to variable glide slopes.
- Protection of residential areas (noise, pollution) thanks to advanced procedures such as RNP to GLS curved approaches with short finals.
- Reduction of fuel burnt through reduced holding circuits due to shorter spacing under LVC.

Capacity KPA

- Resilience in LVC: reduction of delays, diversions, and cancellations due to more efficient operations (reduced LVP spacing between successive approaching aircraft) and increased number of operations when ILS are on maintenance/calibration.
- Improved capacity thanks to enhanced approach procedures such as variable glide slopes, displaced thresholds and second runway aiming points (wake turbulence effect reduction), Insensitivity to snow accumulation, unlike ILS.

Operational Efficiency

- Permits more efficient routes (less time and fuel burnt)
- Improves spectrum efficiency.

Cost Effectiveness

- Several approaches available at the same time to different runway ends and with different glide slopes.
- Enables ILS rationalization (up to 50%, being this scenario -dependant) where there is more than one ILS CAT III installation,
- Reduction in GS maintenance and flight inspections costs.
- Longer life cycle than ILS.

Predictability

- Improves schedule resilience to weather conditions (LVC, fog) reducing delays, cancellations, and diversions.

5 Cost assessment

5.1 Overview of cost assessment approach

The review of the existing CBAs takes the form of discussing their cost items and assumptions. The SESAR 1 cost assessment provides a good description of the individual cost items within different cost domains (regiven in Appendix SESAR 1 D25 cost estimates for reader's convenience) covering deployment, operation and maintenance of a basic GAST D system at a generic airport. The SDM CBA has less detailed categorizaton of the cost items (regiven in Appendix SDM GBAS CBA estimates for reader's convenience) when establishing the costs for deploying and operating a GAST D system. Thus, it is difficult to compare the cost estimates in this CBA with those from the two previous CBAs directly. At best we can comment and discuss the presented CBA scenarios, assumptions, and cost items estimates.

The cost assessment of the CBA at hand is based on the system cost breakdown as shown in Table 6.

Like the approach taken in SESAR 1 D25 CBA, the cost assessment is not related to a specific site. The cost item characterization is kept it as generic as possible. While this choice limits the accuracy of the estimations (the complexity of the area where to deploy the GBAS approach system strongly affects the costs), it supports a clearer and more useful discussion of the cost aspects.

<table>
<tr><th>Segment</th><th>Cost area</th><th>Impacted Stakeholders</th></tr>
<tr><td>Airborne</td><td>Aircraft upgrade to GBAS CAT II/III – out of scope</td><td>Airspace Users</td></tr>
<tr><td rowspan="7">Ground</td><td>Ground Station procurement process preparation and acquisition</td><td rowspan="5">Airports - ANSPs</td></tr>
<tr><td>Initial Training before entry into service</td></tr>
<tr><td>Airport site preparation and Ground Station Installation</td></tr>
<tr><td>Ground station integration to Airport ATM systems</td></tr>
<tr><td>Ground station commissioning and approval</td></tr>
<tr><td>Ground station Operation and Maintenance</td><td></td></tr>
<tr><td>GBAS approach procedure</td><td>ANSPs</td></tr>
</table>

Table 6 GBAS CAT II/III System Costs breakdown

Several cost items are more readily estimated in terms of man hours per year. Also, the cost of a manhour can vary depending on the type of engineer or staff group that is used to perform the activity. Table 7 below provides the background data used to convert from man hours to a monetary value in Euro. The Full-Time Equivalent cost for ANSP staff categories were provided in EUROCONTROL Standard Inputs for Economic Analysis (Dec 2020) [17]. To calculate the hour cost for a staff category, we have divided the FTE value with 1560 work hours/year. The work hours per year was chosen by the solution partners as a reasonable figure (no external official source).

Staff group/Actor	FTE [17]	Labor hourly cost (assuming 1560h/year)
ATCO staff	151000 €	97 €/hour
Support staff (ATSEP)	73000 €	47 €/hour
Engineering staff (ANSPs)	98000 €	63 €/hour

Table 7 Conversion rates used to monetize the cost of manhours estimates

5.2 PJ14-W2-79a cost items and estimates

The starting point for the cost item table below is SESAR 1 D25 [9] classification of cost items but several cost areas are here refined to provide a more details in the cost assessment. A one-to-one comparison of SESAR 1 and PJ14-W2-79a cost estimates is not straightforward. Therefore, discussions relate more to cost areas, refinement of cost items and overall cost differences rather than on the individual cost item differences.

Cost Area	Cost Type	Cost Description	Cost Sub-Category	PJ14-W2-79a estimates k€	Units	Values estimated by
GBAS Ground Station procurement	Other One-off cost	Technical specification (including security and network) and procurement process preparation	Capital costs	40	Per Ground Station	DFS
	Equipment / systems	GAST D Ground Station (4 GNSS antennas, non-redundant, one VDB transmitter), including manufacturer's services	One-off	3500	Per Ground Station	Indra
Initial training before the entry into service	Initial Training & Staffing	Controller's training	One-off	24		ENAIRE
	Initial Training & Staffing	Engineers' training	One-off	41		ENAIRE
	Initial Training & Staffing	ATSEP's training	One-off	45		ENAIRE
Airport site preparation / GBAS GS installation	Other One-off cost	Ground check for geological survey and antenna coordinates survey	One-off	6	Per Ground Station	DFS
	Building & Facilities	Obstacle assessment and frequency application	One-off	5	Per Ground Station	DFS
	Project Management	Planning, drawing and tender process	One-off	75	Per Ground Station	
	Building & Facilities	Standard fundament for antennas, and mast for VDB antenna	One-off	40	Per Ground Station	
	Building & Facilities / Integration costs	Civil engineering work, and connection to the power and network	One-off	180	Per Ground Station	
	Building & Facilities / Integration costs	Shelter incl. delivery and installation	One-off	200	Per Ground Station	
	Installation & Commissioning	Siting study	One-off	600 hours	Per Ground Station	ENAIRE
GBAS GS integration to Airport ATM systems	Integration costs	ATC interface / system interface (for international airports and the first GS)	Capital costs	120	Per Airport	DFS
GBAS GS commissioning and approval	Commissioning and approval	Prepare the basis for the approval	One-off	200 hours	Per Airport	ENAIRE
Ground Station Operation & Maintenance	Training	Continuous Training for ATSEP		75 hours within 5 years since the system is operational. Also when changes on the system are required	Per Airport	ENAIRE
	Other services	Communication lines (for international airports)	Per year	10-100	Per Airport	DFS
	Operating Costs	Performance & RFI monitoring	Per year	6,6		ENAIRE
	Operating Costs	Periodic Verification Flight	Per year	38,4	Per approach procedure	ENAIRE
	Operating Costs	Update of local configuration data & local airport environment in the GS	Per year	3,3		ENAIRE
	Operating Costs	Maintenance of GBAS ground subsystem	Per year	3,6		ENAIRE

	Operating Costs	Maintenance of the auxiliary systems in the GBAS shelter (power, air conditioning, fire-prevention, intrusion detection)	Per year	8,4		ENAIRE
GBAS Approach Procedure	Project Management	Feasibility of GBAS Operation Report	One-off	40 hours	Per procedure	ENAIRE
	Project Management	Ground Validation Report and IFP chart/data	One-off	80 hours	Per procedure	ENAIRE
	Implementation costs	Procedure Design	One-off	140 hours	Per procedure	ENAIRE
	Installation and commissioning costs	Flight Validation Report System verification flight & report; covers 1 approach, 2 h per runway threshold	One-off	9	Per procedure	ENAIRE
	Certification costs	Safety Assessment	One-off	330h/procedure	Per procedure	ENAIRE
	Administrative costs	Procedure Publication	One-off	70 hours	Per procedure	ENAIRE
Avionics and other A/C related expenses				out of scope		N/A

Table 8 PJ14-W2-79a cost items and estimated values

5.2.1 Ground Station procurement process preparation and procurement

This section deals with the cost items related to the cost areas “Ground Station procurement process preparations” and “GBAS GS Procurement in Table 8:

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
Ground Station procurement process preparations	Other One-off cost	Technical specification (including security and network) and procurement process preparation	

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
GBAS Ground Station procurement	Equipment / systems	GAST D Ground Station	Procurement cost of a basic non-redundant GAST D Ground Station consisting of: - 4 GNSS antennas - one VDB transmitter - one Maintenance Data Terminal including manufacturer’s services to install the Ground Station and 4 weeks support and training course.

The GAST D Ground Station procurement cost[3] is estimated to 3.5 M€. The estimate includes the following:

- Site Survey
- Purchase cost of a non-redundant GAST D Ground Station as described in the table above
- FAT
- Installation and configuring
- 4 weeks post-installation support

[3] The procurement cost also includes the relevant monitors that the ground station hosts to address faults such as code-carrier divergence, signal deformation, excessive acceleration, ephemeris fault, and severe ionosphere gradients, in accordance with what has been deemed to be required by SESAR 1, and SESAR 2020 Wave 1 and 2. ICAO Annex 10 Vol I specifies requirements to the performance of these ground monitors.

The procurement cost estimate provided here also includes an RFI monitor and alert function triggering when RFI threat to the Ground Station GNSS received signals is recognised and is affecting performance of the station. The RFI monitor was developed in SESAR 2020 PJ.14-03-01 and validated to TRL4 in wave 1 and TRL6 in wave2.

- Training courses for technical staff and ATC operators

Not included in the cost estimate:

- Site qualification (incl. multipath analysis, local iono analysis report, VDB coverage analysis)
- Civil works required
- (Local) system approval process at airport
- Operations procedure design

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5.2.2 Initial training before entry into service cost

This section deals with the cost items related to the cost area "Initial training before the entry into service" in Table 8:

Cost Area	Cost Type	Cost Item	Detailed Description/Comments (Hourly rates – see Table 7)
Initial training before the entry into service	Initial Training & Staffing	Controller's training	Estimated effort to develop 2-hour course: 48 hours (training material by ATC staff) = 4656 € Cost associated with holding a two-hour course for 100 ATCO: 19400 €. Sum cost for Controller training at large, very large airport: 24056 €
	Initial Training & Staffing	Engineer's training	Estimated training hours: 220 hours per engineer Number of engineers: 4 Sum cost for Engineer training: 55 440 €
	Initial Training & Staffing	ATSEP's training	Estimated training hours: 60 hours (operations & maintenance) 3 hours (technical supervision) Number of ATSEP performing O&M: 11 Number of ATSEP performing technical supervision: 20 Sum cost for ATSEP training: 33 840 €

The number of ATCO, Engineers, and ATSEP used in the table above are representative for the staff of a large, very large airport, which coincides with the defined reference and solution scenario of the CBA.

5.2.3 Ground Station Installation and Qualification cost

This section describes the cost items related to the cost areas "GBAS GS Installation and Airport Site Preparation", "GBAS GS integration to Airport ATM systems", and "GBAS GS commissioning and approval" in Table 8:

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
GBAS GS installation / Airport site preparation	Other One-off cost	Ground check for geological survey and antenna coordinates survey	This task is to check the ground, if it is suitable for the required antenna fundaments (includes check of the ground layers).
	Building & Facilities	Obstacle assessment and frequency application	
	Project Management	Planning, drawing and tender process	The estimate in Table 8 includes construction architect, structural engineering, planning, drawings and call for tender civil works.
	Building & Facilities	Standard fundament for antennas, and mast for VDB antenna	4 GNSS Antennas (1.20 m height) and one VDB Antenna (12 m height)
	Building & Facilities / Integration costs	Civil engineering work, and connection to the power and network	This includes prepare cable ducts, install cable, integrate antenna fundaments, integrate shelter fundament, and manage civil works 140000 € Includes: connection to the uninterrupted power supply system, connection to the ATC or airport communication network and additional overhead such as installation, electrician, crane, lift platform 40000 €
	Building & Facilities / Integration costs	Shelter incl. delivery and installation	Shelter: concrete space cell 120 000 € Installation 70 000 €
	Installation & Commissioning	Siting study	Identify suitable locations, coordination tasks, perform VDB coverage simulations.

Pre-installation costs (preparations before installing):

- Site study
- Local ionosphere report
- Civil works

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
GBAS GS integration to Airport ATM systems	Integration costs	ATC interface / system interface (for international airports and the first GS)	Includes the required adaptation of the Maintenance, Tower and Center systems\tools.
	Equipment / systems	ATC interface / physical interface	Physical interface for the ATC systems installed in the Maintenance, Tower and Center sites

Implementation costs

- costs associated with manufacturer support to install and configure the ground station are included in the GAST D Ground Station procurement cost (see section above).

- ATC interface is an integral part of the GAST D ground station and is included in the GS procurement cost. However, integration cost with the ATC network and systems and any required modification of the ATC system interface or display is covered by the Integration cost estimates in the table above.

- Airport Operator and ANSP costs in this activity

- integration with Airport Infrastructure/network
- integration with ATM/ATC systems

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
GBAS GS commissioning and approval	Commissioning and approval	Prepare the basis for the approval	Declaration of Verification (DoV) and software safety assessment preparation
	Commissioning and approval	Certification cost to regulatory authority	

Commissioning costs

- ANSP/AO cost

Qualification costs

- ANSP/AO cost

- fee to regulatory authority or EASA – not included here

5.2.4 Ground Station Operation & Maintenance

This section describes the cost item related to the cost area “Ground Station Operation and Maintenance” in Table 8:

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
Ground Station Operation & Maintainance	Training	Continuous Training for ATSEP	For operations & maintenance as well as technical supervision tasks
	Other services	Communication lines (for international airports)	
	Operating Costs	Performance & RFI monitoring	Periodic performance analysis, periodic RFI analysis and periodic ground validation. It does not include the cost of the tools necessary for such monitoring and analysis. Estimated Engineering man effort: 140 hours
	Operating Costs	Periodic Verification Flight	Per approach procedure. Includes the verification flight & report. Periodicity: 12 months the first 3 times and 18 months the following ones The estimate in Table 8 is per approach procedure.
	Operating Costs	Update of local configuration data & local airport environment in the GS	Periodic update of local configuration data refers to tropospheric/ionospheric parameters in MT2, magnetic declination, etc. Sporadic update of local airport environment refers to RR masks, multipath parameters, etc. They include parameters update, files management, upload on the system and verification. Cost in Table 8 based on an estimated man effort of 70 hours performed by Engineering staff.
	Operating Costs	Maintenance of GBAS ground subsystem	It includes scheduled and corrective maintenance. It is based on the guidance from ICAO Doc 8071 Volume II plus manufacturer specific testing. Cost in Table 8 based on an estimated man effort of 57 hours performed by ATSEP staff.
	Operating Costs	Maintenance of the auxiliary systems in the GBAS shelter	It includes scheduled and corrective maintenance. It is based on the guidance from ICAO Doc 8071 Volume II plus manufacturer specific testing. Cost in Table 8 based on an estimated man effort of 134 hours performed by ATSEP staff.
	Other services	Support/service	

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Training costs

- ATSEP training

Operating costs

- Performance & RFI monitoring.
- Periodic Verification Flight.
- Update of local configuration data & local airport environment in the GS.

Maintenance costs

- Maintenance of GBAS ground subsystem.
- Maintenance of the auxiliary systems in the GBAS shelter (power, air conditioning, fire-prevention, intrusion detection).

Specific for PJ14-W2-79a subtask T3.2 VDB Measurement Equipment

Within T3.2 "VDB Measurement Equipment" a new VDB measurement antenna was developed with focus to improve work safety (e.g., simple installation of the antenna on the vehicle) and measurement accuracy (verify the ICAO requirement regarding the ±3dB measurement accuracy). Using the new VDB measurement antenna for the maintenance work (e.g., periodical GBAS ground measurements) does not lead to reduction of maintenance costs, because there are still two operators required to perform the work.

5.2.5 GBAS Approach Procedures

This section describes the cost item related to the cost area "GBAS Approach Procedure" in Table 8:

Cost Area	Cost Type	Cost Item	Detailed Description/Comments
GBAS Approach Procedure	Project Management	Feasibility of GBAS Operation Report	Procedure design review and user consultation
	Project Management	Ground Validation Report and IFP chart/data	
	Implementation costs	Procedure Design	Procedure design first version
	Installation and commissioning costs	Flight Validation Report	Per approach procedure. Procedure validation and system verification flight & report. 2 h per runway threshold
	Certification costs	Safety Assessment	
	Administrative costs	Procedure Publication	Publication in AIP

- Procedure design

- Procedure flight validation

- Procedure publication

5.2.6 Airspace User costs – out of scope

There are not airborne manufacturers contributing to SESAR 2020 PJ.14-W2-79a GAST D Extended Scope. Cost estimates relating to avionics and airspace user that were developed in SESAR 1 [9] have not been updated within the scope of SESAR 2020.

6 CBA Model

Cost assessment tables with corresponding discussions are included in section **Error! Reference source not found.**.

6.1 Data sources

Data sources are:

- CBAs listed in reference section of this document [9], [10], [11], [12]

- Data input for economic analyses [17]

- Partners contributions to the CBAs (stakeholders and experts)

- ENAIRE/AENA
- ENAV
- EUROCONTROL
- DFS
- SINTEF
- Indra

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7 CBA Results

The benefits of deploying GAST D as next generation precision approach system replacing current ILS CAT II/III in Europe is revisited (elaborated in SESAR Deployment Manager (SDM) GBAS Business Case). The monetized benefits as presented in SDM CBA and qualitatively listed in section 4 are found equally applicable for the solution scenarios defined in this CBA, namely GAST D replacing ILS CAT III in airports located in non-mid latitude European regions given similar traffic load and operating environment. The non-mid latitude European regions may encounter periods of adverse ionosphere gradients and scintillation that can impact the availability of the GAST D service during the most severe occurrences. The effect will be site dependent and vary temporally, thus requiring local assessment and measures to consider the local variations.

The SESAR 1 15.03.06 D25 GAST D cost assessment covering the GBAS ground station procurement and the related installation, commissioning, Operation and Maintenance have been reviewed. The assessment addresses a generic GAST D scenario and is not related to a specific installation site. To have full control of the definition and content of each cost item, new cost items are defined and associated with cost estimates instead of updating the D25 cost estimates from wave 1. The new cost table (Table 8) has more detailed categorization of cost items. The estimates reflect that the cost level and knowledge of the GAST D system has increased since wave 1 (2106).

Revision and refinement of the cost items are provided by the SESAR 2020 PJ.14-W2-79a GAST D Extended Scope solution partners represented by ANSPs, Ground Station manufacturer, and research institutes. As no GBAS airborne receiver manufacturers are participating in the wave 2 PJ.14-W2-79a solution, this report does not include any re-assessment or additional data related to airborne receiver cost.

All the quantified costs appearing in this report must be considered as approximate, ROM estimations, and they do not constitute any form of commitment of the companies providing the data.

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8 Sensitivity and risk analysis

In the Benefits section it is argued that the SESAR Deployment Manager CBA is valid also for PJ14-W2-79a GAST D Extended Scope. Thus, the sensitivity and risk analysis carried out by SDM within [10] applies. No additional sensitivity or risk analysis has been carried out.

9 Recommendations and next steps

PJ14.W2-79a is a technological solution. Operational benefits are not addressed in this CBA. To obtain a complete picture of the costs and benefits associated with replacing the current ILS systems with GBAS solutions, both the technological and the operational benefits need to be considered. A continuation of the SESAR Deployment Manager CBA to include benefits validated in the wave 2 SESAR 2020 operational solutions and Very Large Demonstration (VLD1 DREAMS) would provide a more comprehensive picture of the benefits.

Discussions within the ATM community are on-going regarding GBAS deployment strategies. The SDM GBAS CBA (2020) refers to the ICAO recommendations that although the ultimate GNSS goal is operating on dual frequencies and multiple satellite constellations (DFMC), industrialisation would benefit from a stepwise approach, starting with GAST D followed with GAST F implementation. ICAO NSP GBAS Working Group (GWG) confirmed during Jwgs/9 June 2022 that it is necessary to implement GBAS GAST D operationally as a step from ILS CAT III to more advanced forms of GBAS CAT III, such as ultimately DFMC GBAS.

10 References and Applicable Documents

10.1 Applicable Documents

[1] SESAR Project Handbook;

[2] Guidelines for Producing Benefit and Impact Mechanisms;

[3] Methods to Assess Costs and Monetise Benefits;

[4] SESAR 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] SESAR 1 15.03.06 D25 GBAS CAT II/III L1 Cost Assessment Report, Ed. 00.02.00, September 2015

[10] SESAR Deployment Manager GBAS Business Case, Release 1, 2020

[11] SESAR 1 16.06.06 D51 SESAR 1 Business Case – Consolidated Deliverable with contributions from 16.06.01-16.06.02-16.06.03-16.06.05, Ed. 00.01.01, July 2016

[12] SESAR 2020 PJ20 D2.6 (AMPLE) Consolidated Business Case (2018) and (2019), Ed. 00.01.00, Sept 2019

[13] SESAR 2020 D9.1.110 PJ.14-W2-79a TS/IRS GAST D Extended Scope, Ed. 01.01.00, July 2022

[14] SESAR 2020 D9.1.400 PJ.14-W2-79a TVALR GAST D Extended Scope, Ed. 01.00.00, July 2022

[15] SESAR 2020 D9.3.120 PJ.14-W2-79 European Ionosphere Threat Report, Ed. 00.01.02, June 2022

[16] ICAO JWGS/8, WP/26, November 2021, Guidance Material on Characterization of Ionospheric Threat Model for GBAS

[17] EUROCONTROL Standard Inputs for Economic Analysis, Ed. 9.0, December 2020

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11 Appendix

11.1 General comments

The SESAR Deployment Manager CBA analysed the cost benefit of replacing ILS CAT III installations with GAST D systems at 16 European airports for two different GBAS deployment strategies. The scenarios in the SDM CBA are based on

- the selected airports were all located in mid-latitude regions operating under nominal conditions
- the operational environments (OE) of the selected airports were characterized as large and very large

whereas in this CBA we have defined the scenarios as

- airports located in non-mid latitude regions prone to adverse atmosphere conditions
- the operational environments of the selected airports include medium in addition to large and very large.

The reason for including medium size OE is that many airports located in non-mid latitude regions are medium size. Such airports are candidates for GAST D deployment. It would be unrealistic to exclude them. For the SDM CBA, large and extra-large OE was relevant given that the SDM CBA was to provide input to the Common Projects 2 programme as well as the selected large and very large airports were more natural candidates for the initial GBAS deployment strategy.

Solution 79a verifies the feasibility of GAST D operating in areas prone to adverse ionosphere and scintillation occurrences. The European Ionosphere Threat Report issued yearly by EUROCONTROL, clearly shows a geographical and temporal (seasonal as well as time of day) variation in the vulnerability to severe ionosphere gradients, also locally within the non-mid latitude regions. Given this variation, we can not make a general statement applicable to all airports located in these regions regarding how adverse atmosphere conditions will impact the GAST D deployment and operation. Section 11.2 below discusses in more detail the adverse atmosphere impact on factors such as siting and availability of GAST D service and in turn how this may impact a local CBA.

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11.2 Impact of PJ.14-W2-79a ST3.1.1. Ionosphere monitoring and analysis

This subtask ST3.1.1 Ionosphere monitoring and analysis aimed at closing an open item remaining at the end of SESAR 1 15.03.06; namely validating the GAST D performance when operating under adverse atmosphere conditions. Work in wave 1 and wave 2 have used data collected by a GBAS data logger station installed at Tenerife Norte airport. This location was chosen as it is within the Equatorial region, where relevant adverse ionospheric activity was expected. The subtask developed monitoring algorithms, and validation activities were carried out to verify GAST D performance [13] using real data from Tenerife Norte.

The T3.1.1 validation of the GAST D Ground Station performance when encountering adverse ionosphere, scintillation, and troposphere conditions do not impact the CBA estimates in the two existing CBA reports considered herein. These CBA report scenarios are based on GAST D operating in Europe. Since 2012, EUROCONTROL has published data annually [14] related to ionosphere gradients (occurrence and severity) for many locations in Europe, covering low, mid-, and high latitude regions in support of current and future GBAS implementations in Europe. The ionosphere gradient location analysis has shown that most of the gradients are occurring either at low latitude (below 35°N) or high latitude (above 60°N). In addition, the analysis of the gradient time of occurrence has shown that most of the gradients occurred around the equinoxes and during local night hours.

As large gradients do occur, it is essential that the GAST D station can meet the ICAO integrity and continuity requirements in all situations. The validation shows that the GAST D station has the potential to operate safely under ionospheric gradients, and that ionospheric disturbances (gradients, plasma bubbles and scintillations) are sufficiently rare and benign that they do not have a significant impact on availability. Therefore, the benefit assessment performed in SDM GBAS CBA [10] can be extended to be valid also for airports in high and low latitude, provided the operational conditions are similar.

Activities that have taken place within the ionospheric activities in PJ.14-W2-79a have shown that GBAS GAST D can provide CAT III service with sufficient integrity, continuity and availability in the ionospheric conditions that have been studied in the solution. There are two findings that are relevant for the business case:

- Plasma bubbles will be a driver for siting constraints, as they are steep and short, and may therefore, to a larger extent than the ionospheric gradients that have been studied previously, “hide” between the aircraft and the ground station
- Under these conditions (gradients/plasma bubbles that are steeper and shorter than the ICAO ionospheric model), siting distances are shorter than the ideal 5 km.

As a consequence of this:

- When studying local ionospheric conditions to establish a local ionospheric model, it must be determined what is the lower limit for gradient/plasma bubble width. This fact has been presented to ICAO [15]
- Where such conditions are present (gradients/plasma bubbles steeper and shorter than the ICAO model), large airports may require two GBAS stations, or accept that the availability for remote runway ends may, under conditions of reduced constellation states (such as 27 SV or less), is below 0.99.

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- Quantification needs to be addressed per local CBA.

11.3 Impact of PJ.14-W2-79a ST3.2 VDB Measurement Equipment

This Solution 79a subtask continues the SESAR 1 and SESAR 2020 wave 1 development of a GBAS Measurement Tool (GMT) used to verify the performance of a GBAS Ground Station and the power flux density of the GBAS VDB signal on the ground. The focus in wave 2 is the introduction of a new VDB measurement antenna which is validated against the ICAO Doc 8071 Vol. II ±3dB measurement uncertainty requirement. This uncertainty includes the measurement equipment (characterized in Wave 1), the calibration of the measurement setup with installed antenna on a vehicle and the measurement antenna itself

The measurement equipment and the outcome of the validation exercises do not directly impact this CBA. Although accurate and efficient operation and maintenance equipment is important for cost efficiency of installing, commissioning, operating, and maintaining the GBAS ground system at an airport, the corresponding cost items in the CBA estimates in section **Error! Reference source not found.** cover this.

It is worth noting that such operation and maintenance equipment is often not dedicated to a given technology or specific service deployed at the airport but can be used for multiple purposes. Specialized equipment is in many cases not continuously in use at one site and can be shared between multiple installations at different airports.

11.4 Impact of PJ.14-W2-79a ST3.3 GBAS Ground Station RFI Threat

This subtask of Solution 79a had the following targets:

- Increase the robustness of the GBAS ground subsystem, to increase the probability of the ground station to coast through an interference event, and ensure that it can do it safely, in the sense that errors are still bounded under the impact of the additional noise. This work has resulted in additional software algorithms in the ground station, and therefore no additional cost of the ground subsystem. This includes algorithms to detect RFI that the GBAS subsystem is exposed to and provide warnings to the operator.

- Characterize the typical environment, so that it is possible to estimate the magnitude of the RFI problem

The SDM GBAS CBA [9] has the underlying assumption that unlawful interference is managed. However, it also assumes that airports maintain some conventional infrastructure for resilience purposes. It is not possible to compute any potential availability reduction due to RFI since neither the RFI itself nor the spectrum management law enforcement are stochastic processes. Therefore, the business case must assume that RFI is kept on an acceptable level and that the conventional infrastructure is kept for exceptional cases. The technical work carried out in Solution 79a increases the robustness of the ground subsystem to the extent possible and ensures integrity is maintained but it is not possible to fully prevent availability impacts without strict enforcement of spectrum use.

The work carried out in Solution 79a does not impact the conclusions of the existing CBA.

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12 Appendix SESAR 1 D25 cost estimates

Table 9 is extracted from SESAR 1 D25 CBA for reader's convenience. For details and explanations, the reader is referred to [9].

Cost Name	Cost Type	Cost Description	Cost Sub-Category	Values SESAR 1 estimates - at Jan 2015 values k€	Units	Values estimated by
GBAS Ground Station procurement	Equipment / systems	GAST D Ground Station (4 GNSS antennas, non-redundant, one VDB transmitter), including manufacturer's services	One-off	1500 – 2500	Per Ground Station	SESAR 1: INDRA – THALES (Ground Stations manufacturers)
GBAS Ground Station procurement	Other One-off cost	Ground check for geological survey and antenna coordinates survey	One-off	6	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Building & Facilities	Obstacle assessment and frequency application	One-off	1 - 3	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Project Management	Planning, drawing and tender process	One-off	30 - 50	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Building & Facilities	Standard fundament for antennas, and mast for VDB antenna	One-off	16 - 20	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Building & Facilities / Integration costs	Civil engineering work, and connection to the power and network	One-off	120 - 139	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Building & Facilities / Integration costs	Shelter incl. delivery and installation	One-off	60 - 90	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Integration costs	ATC interface / system interface (for international airports and the first GS)	One-off	105	Per Airport	SESAR 1: DFS (ANSP)
	Integration costs	ATC interface / physical interface	One-off	10 - 15	Per Ground Station	SESAR 1: DFS - DSNA (ANSP's)
	Installation & Commissioning	Site survey/qualification/acceptance	One-off	27	Per Ground Station	SESAR 1: DSNA (ANSP)
Ground Station Operation & Maintenance	Hardware & Software	Service Level 1	Maintenance & Repair	5 per year	Per Ground Station	SESAR 1: DFS (ANSP)
	Hardware & Software / Training	Service Level 2	Maintenance & Repair	25 per year	Per Ground Station	SESAR 1: DFS (ANSP)
	Hardware & Software / Training	Service Level 3	Maintenance & Repair	26 per year	Per Ground Station	SESAR 1: DFS (ANSP)
	Other services	Communication lines (for international airports)	Maintenance & Repair	10 - 100 per year	Per Airport	SESAR 1: DFS (ANSP)
	Other services	Support	Maintenance & Repair	40	Per Ground Station	SESAR 1: DFS (ANSP)
GBAS Approach Procedure	Project Management	Feasibility of GBAS Operation Report	One-off	2 - 5	Per procedure	SESAR 1: ENAIRE (ANSP)
	Project Management	Ground Validation Report and IFP chart/data	One-off	7 - 18	Per procedure	SESAR 1: ENAIRE (ANSP)
	Installation and commissioning costs	Flight Validation Report	One-off	7 - 16	Per procedure	SESAR 1: ENAIRE (ANSP)
	Certification costs	Safety Assessment	One-off	35 - 85	Per procedure	SESAR 1: ENAIRE (ANSP)
	Administrative costs	Procedure Publication	One-off	3 - 8	Per procedure	SESAR 1: ENAIRE (ANSP)
Regional TP Aircraft upgrade to GBAS	Equipment/ systems	Regional Turboprop aircraft upgrade to GBAS CAT II – Forward fit case	One-off	190 - 230	Per Aircraft	SESAR 1: Alenia Aermacchi (Aircraft Manufacturer)
	Equipment/ systems	Regional Turboprop aircraft upgrade to GBAS CAT II – Retrofit case	One-off	220 - 260	Per Aircraft	SESAR 1: Alenia Aermacchi (Aircraft Manufacturer)

Table 9 SESAR 1 D25 GBAS CBA cost estimates per cost item

13 Appendix SDM GBAS CBA estimates

Table 10 is extracted from SESAR Deployment Management CBA for reader's convenience. For details and explanations, the reader is referred to [11].

Cost Name	Cost Type	Cost Description	Cost Sub-Category	Values SDM estimates – at Jan 2020 values k€	Units	Values estimated by
GBAS Ground Station procurement	Equipment / systems	GAST D Ground Station (4 GNSS antennas, non-redundant, one VDB transmitter), including manufacturer's services	One-off	3500	Per Ground Station	SESAR Deployment Manager members
	Equipment / systems	Upgrade from GBAS CAT I to GBAS CAT II/III	One-off	2500	Per upgrade	SESAR Deployment Manager members
Ground Station Installation & qualification	GBAS Infrastructure*	*) Includes integration of GBAS data into ANSP/ Airport systems and relevant ATCO training.	One-off	Small airport environment: 1500 Medium airport environment: 2500 Large airport environment: 3500	Per GBAS integration	SESAR Deployment Manager members

Table 10 SESAR Deployment Manager (SDM) GBAS CBA cost estimates per cost item

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