EGNOS AVIATION SERVICES EVOLUTION (EASE)

FINAL REPORT
### DOCUMENT REVIEW

| Drafted by: | EASE consortium | Date: 12/04/19 |
| Verified by: | Anne Cloerec | Date: 12/04/19 |
| Authorised by: | Anne Cloerec | Date: 20/06/19 |

### DOCUMENT LOG

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Description of evolution</th>
<th>Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>12/04/19</td>
<td>First version of the document</td>
<td>-</td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td>Addition of WP1.2 results</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>28/05/19</td>
<td>Final version following Final Review Meeting and GSA comments</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>20/06/19</td>
<td>Final version</td>
<td></td>
</tr>
</tbody>
</table>

### DOCUMENT APPROVAL

<table>
<thead>
<tr>
<th>Approved by:</th>
<th>Name</th>
<th>Role &amp; Organisation</th>
<th>Date</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anne Cloerec</td>
<td>Project Manager Egis</td>
<td>20/06/2019</td>
<td></td>
</tr>
<tr>
<td>Approved by:</td>
<td>Pierre Durel</td>
<td>Project Officer GSA</td>
<td>20/06/2019</td>
<td></td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

1 EXECUTIVE SUMMARY .............................................................................................................. 4

2 INTRODUCTION .......................................................................................................................... 7

2.1 CONTEXT .................................................................................................................................. 7

2.2 PROJECT OBJECTIVES ........................................................................................................... 7

2.3 PROJECT ORGANISATION ....................................................................................................... 7

2.4 ACRONYMS ............................................................................................................................... 7

2.5 DOCUMENT STRUCTURE .......................................................................................................... 8

3 APPROACH .................................................................................................................................. 9

4 OVERVIEW OF THE RESULTS PER NEW EGNOS SERVICE .................................................. 11

4.1 EGNOS ENABLED ADS-B BASED SERVICE ......................................................................... 11

4.1.1 Identification of potential new EGNOS-enabled ADS-B applications ................................ 11

4.1.2 SBAS performance requirements to support ADS-B applications ..................................... 12

4.1.3 Safety risk analysis .............................................................................................................. 13

4.1.4 Service provision ................................................................................................................ 14

4.1.5 Implementation timeline .................................................................................................... 14

4.1.6 Cost Benefits Analysis ......................................................................................................... 16

4.2 EGNOS VERTICAL REFERENCE SERVICE ....................................................................... 19

4.2.1 Identification of future new service .................................................................................... 19

4.2.2 Regulatory analysis ............................................................................................................ 21

4.2.3 Service implementation ...................................................................................................... 22

4.2.4 Service provider analysis .................................................................................................. 23

4.2.5 Implementation timeline .................................................................................................... 23

4.2.6 Cost benefits analysis ......................................................................................................... 24

4.3 SBAS AUTHENTICATION SERVICE ..................................................................................... 28

4.3.1 Background ........................................................................................................................ 28

4.3.2 Key Management proposed Approach ............................................................................ 28

4.3.3 Business model .................................................................................................................. 29

4.3.4 Implementation road map .................................................................................................. 30

4.3.5 Cost evaluation ................................................................................................................... 31

4.4 POTENTIAL EGNOS APPROACH SERVICES BEYOND CAT I ........................................ 32

4.4.1 Identification of potential new EGNOS approach services beyond CAT I ...................... 32

4.4.2 Operational needs in Europe for potential SBAS approach services with minimum beyond CAT I .................................................................................................................. 32

4.4.3 EGNOS performance requirements to potentially support SA CAT I and CAT II33 35

4.4.4 Safety analysis ................................................................................................................... 35

4.4.5 Costs and benefits .............................................................................................................. 36

5 CONCLUSIONS AND WAYFORWARD ..................................................................................... 39

5.1 FUTURE POTENTIAL EGNOS SERVICES .......................................................................... 39

5.1.1 List of proposed new EGNOS based services ................................................................. 39

5.1.2 Consolidated SBAS requirements ..................................................................................... 40

5.1.3 Feasibility study ................................................................................................................. 44

5.1.4 Safety analysis ................................................................................................................... 46

5.1.5 Service provision .............................................................................................................. 46

5.1.6 Implementation timeline .................................................................................................. 46

5.1.7 Cost and Benefits .............................................................................................................. 47

5.2 WAY FORWARD ...................................................................................................................... 51
1 EXECUTIVE SUMMARY

“EGNOS Aviation Services Evolution” (EASE) in an H2020 project funded by the European Commission that aims at supporting the roadmap definition for the long-term evolution of the EGNOS programme. The EASE project consortium members are Egis (leader) and Thales Alenia Space.

The evolutions of EGNOS services for aviation safety beyond 2025 could take any of the following three directions:

- Enlarge the provision of EGNOS services to Communication Navigation Surveillance (CNS) and Air Traffic Management (ATM) beyond navigation, notably to address surveillance (ADS-B) and possibly support timing services for communication systems;
- Provide additional features to increase the robustness against external intentional or unintentional threats/attacks to the EGNOS navigation service, for instance by adding authentication to GNSS signals or ad hoc features at antenna and receiver level;
- Enhance the navigation, positioning and/or timing performance provided at user level, for instance by improving the vertical position accuracy and the time-to-alert to enable supporting Cat-II approach procedures.

The objective of the EASE project is to analyse and define the reasons motivating evolutions along those three axes beyond 2025, determine constraints and prerequisite and assess the added value to end-users.

The approach adopted to investigate the three directions of improvement rely on three interrelated tasks, as follows:

- **Definition of the user requirements**: the objective is to identify the set of SBAS technical requirements corresponding to the new service: starting from the analysis of the operational needs of the ATM community, a set of user requirements are defined and then translated into technical SBAS requirements.
- **Regulatory framework and safety analysis**: the objective is twofold:
  - To identify the constraints that will need to be satisfied before the new service could be implemented operationally. As a pan-European satellite navigation system, EGNOS provides a Safety of Life (SoL) Service, which supports transport application, inter alia, aviation’s safety critical applications. The provision of a new service for ATM purposes falls under the SES regulations and associated processes, for which the European Aviation Safety Agency (EASA) plays a key role.
  - To perform a safety analysis by analysing the operational hazards and identifying potential mitigations means.
- **Added value for aviation end users and implementation timeline**: the objective is to analyse the added value for aviation end users and define how the service could be provided, in order to enable a programmatic decision on which service should be implemented as a priority.

The stakeholder consultation process allowed identifying and selecting the following applications:

- **Enhanced A-SMGCS application**: ADS-B is used to enhance the surveillance quality (by providing an additional surveillance means) at airports already equipped with A-SMGCS. This solution allows improving the A-SMGCS alerts
and routing function (e.g. Follow the green function) or may also enable the implementation of additional alerts.

- **Alternative A-SMGCS applications**: ADS-B is used as a sole means to provide an alternative surveillance means with the required performances for an “A-SMGCS like”, i.e. an A-SMGCS with possibly a reduced number of alerts or functions.

- **SURF-IA (Enhanced Traffic Situational Awareness on The Airport Surface With Indications and Alerts)**: it consists in providing flight crew with visual awareness on the airport moving map display and indications and alerts (aural and on devices) about situations where collision hazard exists or a collision appears imminent.

- **SURF-A** consists in providing alerts to the pilot with respect to surrounding traffic during runway operations to prevent collision on the runway. SURF-A is similar to SURF-IA but does not include the use of a Cockpit Display of Traffic Information (CDTI) and the provision of indication.

- **EGNOS Vertical reference service**: EGNOS is used as a new altitude reference system; geodetic altitude is used instead of barometric pressure measurements to calculate the altitude.

- **Special Authorisation (SA) CAT I operations**: SA CAT I approaches are introduced as an operational credit to extend the instrument segment of a CAT I approach to allow CAT I operations down to a DH of 150 ft, subject to holding specific approval from the competent authority.

- **CAT II operations**: equivalent to current CAT II operations.

In addition, assessment of constraints to implement a **SBAS authentication service** in the aviation context has been performed.

**Consolidated SBAS requirements**

No explicit requirements (e.g. in term of accuracy, integrity, availability) have been defined so far for the ADS-B surveillance source for alternative or enhanced A-SMGCS applications. Consequently tentative ones (e.g. for accuracy) have been proposed from a comparison with the ones from other existing means of surveillance. For SURF-IA, ADS-B requirements have been defined in the RTCA standard and for SURF-A, ADS-B requirements have been proposed by the manufacturer as part of the SESAR project. So far, the most stringent requirements concerned the accuracy of the position for which NACp equal to 10 or 11 would be required (i.e. an accuracy < 10m or 3m). For the EGNOS Vertical reference service, a set of requirements have been proposed based on stakeholder consultations. Lastly, Egis proposed requirements for SA CAT I with accuracy requirements obtained by linearization of ILS CAT I performance at a DH of 150 ft, and HAL/VAL requirements derived by scaling the accuracy by 2.5. The presented CAT II requirements are based on equivalency of ILS CAT II requirements for information purposes only. However, it is recommended to derive SBAS CAT II requirements considering SBAS characteristics and its integration within the aircraft.

**Safety analysis**

The preliminary safety analysis that were conducted (both for the use of the same source of position for navigation and surveillance, and on beyond CAT I operations) indicated that the use of EGNOS for future service does have major impact on the EGNOS V3 system in general (i.e. ground system and receivers which are already DAL B certified).
Concerning the authentication service, the use of the authentication may increase the likelihood of loss of EGNOS service. SBAS authentication scheme should be designed to limit this increase. Moreover, the authentication function would need to be designed in a way it ensures high levels of availability and continuity (since it contributes to the loss of EGNOS service).

**Service provision**

From a service point of view, the new services (i.e. EGNOS-enabled ADS-B services and vertical reference service) could be categorised as a constituent service for Navigation and there is no need to have a different service provider.

Similarly, for authentication service, no specific advantage has been identified for using an operator different from the SBAS one.

The provision of the new services (i.e. EGNOS-enabled ADS-B services and vertical reference service) would oblige the EGNOS Service Provider (ESP) to complete a safety assessment for the functional change but it would not require them to set up new processes for safety oversight and safety performance monitoring.

The definition of specific Service Level(s) (SL) of the EGNOS Safety of Life service associated with the new services may be required but this would need to be confirmed by airworthiness authorities and the EGNOS service provider.

**Costs and Benefits analysis**

For ADS-B operations and beyond CAT I operations, the benefits have been calculated per segment considering small, medium and large/very large airports and the average number of movements on these airports and a typical aircraft per type of airport for the airspace user perspective.

Benefits associated with A-SMGCS applications, have been quantified based on:

- For Airspace users, fuel savings resulting from taxitime optimization;
- For ANSP, safety benefits associated with continuity of the revenue that could result from a decrease of the impact on incident on the continuity of airport activities.

Benefits for both SA CAT I and SBAS CAT II services have been quantified based on:

- For ANSPs, a reduction of the loss of revenues due to the capacity gained during adverse weather conditions;
- For Airspace Users, a reduction of delay and diversion costs.

For the vertical reference service, the benefits have been quantified for the ECAC traffic and aircraft fleet only, in term of fuel savings for airspace users and increased capacity for ANSP, making distinction between oceanic and continental traffic.
2 INTRODUCTION

The objective of this EASE Final Report document is to present the main results of the EASE project.

2.1 Context

The European Commission is defining the long term evolution of the EGNOS programme beyond the EGNOS Service Release of EGNOS V3 currently defined. Evolution shall support the implementation of safer and more efficient aviation operations. In this sense, the evolutions of EGNOS services for aviation safety beyond 2025 could take any of the following three directions:

- Enlarge the provision of EGNOS services to Communication Navigation Surveillance (CNS) and Air Traffic Management (ATM) beyond navigation, notably to address surveillance (ADS-B) and possibly support timing services for communication systems;
- Provide additional features to increase the robustness against external intentional or unintentional threats/attacks to the EGNOS navigation service, for instance by adding authentication to GNSS signals or ad hoc features at antenna and receiver level;
- Enhance the navigation, positioning and/or timing performance provided at user level, for instance by improving the vertical position accuracy and the time-to-alert to enable supporting Cat-II approach procedures.

2.2 Project objectives

The “EGNOS Aviation Services Evolution” (EASE) project aims at supporting the roadmap definition for the long-term evolution of the EGNOS programme.

The objective of the EASE project is to identify possible new services that would benefit from EGNOS V3 and beyond, analyse and define the reasons motivating evolutions along these services, determine associated constraints and pre-requisite and assess the added value to end-users.

2.3 Project Organisation

The EASE project is a H2020 project funded by the European Commission. It is a one-year project from April 2018 to April 2019.

The EASE consortium is led by Egis Avia and includes Helios and Thales Alenia Space.

The project is organised into four Work Packages (WP), each WP being responsible to investigate one type of potential new EGNOS services.

2.4 Acronyms

The following acronyms are used in this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS-B</td>
<td>Automatic Dependent Surveillance- Broadcast</td>
</tr>
<tr>
<td>ANSP</td>
<td>Air National Service Provider</td>
</tr>
<tr>
<td>AU</td>
<td>Airspace Users</td>
</tr>
<tr>
<td>CA</td>
<td>Commercial Aircraft</td>
</tr>
</tbody>
</table>
2.5 Document structure

The document is structured as follows:

Section 1 is the executive summary.

Section 2 is the introduction of the document, including the context, the project objective and the organisation.

Section 3 describes the approach adopted to meet the objective of the project

Section 4 presents an overview of the main results per type of new EGNOS service.

Section 5 presents the consolidated conclusions and the wayforward.
3 APPROACH

The approach adopted to investigate the three directions of improvement rely on three interrelated tasks, which are summarised in the following figure.

- **Definition of the user requirements**: the objective is to identify the set of SBAS technical requirements corresponding to the new service: starting from the analysis of the operational needs of the ATM community, a set of user requirements are defined and then translated into technical SBAS requirements.

- **Regulatory framework and safety analysis**: the objective is twofold:
  
  o To identify the constraints that will need to be satisfied before the new service could be implemented operationally. As a pan-European satellite navigation system, EGNOS provides a Safety of Life (SoL) Service, which supports transport application, inter alia, aviation’s safety critical applications. The provision of a new service for ATM purposes falls under the SES regulations and associated processes, for which the European Aviation Safety Agency (EASA) plays a key role.

  o To perform a safety analysis by analysing the operational hazards and identifying potential mitigations means.

- **Added value for aviation end users and implementation timeline**: the objective is to analyse the added value for aviation end users and define how the service could be provided, in order to enable a programmatic decision on which service should be implemented as a priority.

  The analysis considers the following areas:

  o The technical feasibility of the service to determine if the technological development is mature enough to support the provision of the selected service;
- The identification of viable Business Models and associated recommended Service Provision Schemes ensuring that the overall business is feasible and profitable to users;

- The Implementation Timeline; and

- The Cost and Benefits Analysis (CBA) for the relevant categories of future service users (ANSP, Airspace Users, ESP…);

The CBA’s goal for this study has been to identify and highlight the benefits and costs for ANSPs and Airspace Users to implement new operations based on EGNOS v3 services in the considered timeframe 2025-2040. The role of this CBA is to provide a better understanding of the conditions in which the end users would be interested in implementing such operations based on new EGNOS v3 services and what could be their incentive and willingness. The results are provided in the form of a SWOT (Strengths, Weakness, Opportunities and Threats).
4 OVERVIEW OF THE RESULTS PER NEW EGNOS SERVICE

4.1 EGNOS enabled ADS-B based service

4.1.1 Identification of potential new EGNOS-enabled ADS-B applications

The consolidation of the current ADS-B based activities (e.g. from SESAR projects and FAA activities) and the stakeholder consultations allowed identifying four ADS-B applications that would benefit from the use of SBAS to satisfy their potential requirements. These applications concerned the airport environment.

- **Enhanced A-SMGCS (Advanced Surface Movement Guidance and Control System)**
  - This “Enhanced A-SMGCS” application refers to the use of ADS-B to improve the surveillance quality by adding an additional surveillance means in order to enhance A-SMGCS with optimisation of the existing alerts and enable the new functions.
  - A-SMGCS is already deployed at some major European airports based on Surface Movement Radar and multilateration surveillance systems. The PCP regulation (EU) No 716/2014 imposes that by 2021, 24 major European airports will have to implement a set of safety nets provided by A-SMGCS on the airport surface.
  - The use of ADS-B based on SBAS would allow providing an additional surveillance layer with the required performances for “Enhanced A-SMGCS”.

- **Alternative A-SMGCS**
  - “Alternative A-SMGCS” refers to an “A-SMGCS like” based on alternative solutions for surveillance sensors. This “A-SMGCS like” would include a subset of functions and alerts compared to the existing A-SMGCS, as standardised in ED87.
  - This “Alternative A-SMGCS” is envisaged to be deployed at secondary airports that do not plan to deploy multilateration. A non-cooperative surveillance means would be still required for non-equipped aircraft.
  - The use of ADS-B based on SBAS would allow providing a single layer of surveillance with the required performance for “Alternative A-SMGCS”.

- **SURF-IA (Enhanced Traffic Situational Awareness on The Airport Surface With Indications and Alerts)**
  - SURF-IA application consists in providing flight crew with visual awareness on the airport moving map display and indications and alerts (aural and on devices) about situations where collision hazard exists or a collision appears imminent.
  - SURF-IA has been standardised by RTCA (with a dedicated Safety and Performance Requirements (SPR) document) but not by EUROCAE.
  - The use of ADS-B based on SBAS would allow meeting the accuracy requirements (in particular, the ones defined for small airports).

- **SURF-A (Surface Alert)**
  - SURF-A consists in providing alerts to the pilot with respect to surrounding traffic during runway operations to prevent collision on the runway. SURF-A
is similar to SURF-IA but does not include the use of a Cockpit Display of Traffic Information (CDTI) and the provision of indication.

- SURF-A is currently under development within the SESAR project.
- SURF-A is not a driver for SBAS but the use of ADS-B based on SBAS could allow providing a better accuracy.

### 4.1.2 SBAS performance requirements to support ADS-B applications

No explicit requirements (e.g. in term of accuracy, integrity, availability) have been defined so far for the ADS-B surveillance source for alternative or enhanced A- SMGCS applications. Consequently tentative ones (e.g. for accuracy and availability) have been proposed from a comparison with the ones from other existing means of surveillance. For SURF-IA, ADS-B requirements have been defined in the RTCA standard and for SURF-A, ADS-B requirements have been proposed by the manufacturer as part of the SESAR project. So far, the most stringent requirements concerned the accuracy of the position for which NACp equal to 10 or 11 would be required (an accuracy < 10m or 3m).

*Note: It is premature to have definitive requirements. A conservative approach has been taken to derive the most realistic stringent surveillance requirements from a SBAS perspective.*

From all these ADS-B requirements, an allocation for the SBAS system has been performed and associated requirements have been obtained from the quantization of the quality indicators. The resulting SBAS requirements are listed in Table 1.

<table>
<thead>
<tr>
<th>Operations Indicators</th>
<th>ADS-B to support enhanced A- SMGCS (Note 1)</th>
<th>ADS-B to support alternative A-SMGCS (Note 2)</th>
<th>SURF-A</th>
<th>SURF-IA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal accuracy 95%</strong></td>
<td>&lt; 10m (NACp=10) or &lt; 3m (NACp = 11)</td>
<td>&lt; 10m (NACp=10)</td>
<td>&lt; 30m (NACp = 9) But &lt; 10m recommended (NACp=10)</td>
<td>&lt; 3m (NACp = 11) to &lt; 30m (NACp = 9)</td>
</tr>
<tr>
<td><strong>Vertical accuracy 95%</strong></td>
<td>≤45 m (Note 3)</td>
<td>≤45 m (Note 3)</td>
<td>≤45 m</td>
<td>≤45 m</td>
</tr>
<tr>
<td><strong>Integrity risk</strong></td>
<td>≥ 10⁻⁷</td>
<td>≥ 10⁻⁷</td>
<td>10⁻⁵</td>
<td>10⁻⁴ for indication and caution and 10⁻⁵ for warning</td>
</tr>
<tr>
<td><strong>Time to alert (TTA)</strong></td>
<td>Tbd</td>
<td>≤10s</td>
<td>≤10s</td>
<td>≤10s</td>
</tr>
<tr>
<td><strong>Horizontal Alert Level (HAL)</strong></td>
<td>Tbd</td>
<td>Tbd</td>
<td>&lt; 0.1 NM (NIC=8)</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Vertical Alert Level (VAL)</strong></td>
<td>Tbd</td>
<td>Tbd</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Continuity risk</strong></td>
<td>Tbd</td>
<td>10⁻⁵</td>
<td>10⁻³</td>
<td>10⁻³</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>Tbd</td>
<td>≥ 99.99%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Horizontal Velocity</strong></td>
<td>&lt; 3m/s</td>
<td>&lt; 3m/s</td>
<td>&lt; 10m/s</td>
<td>&lt; 10m/s</td>
</tr>
</tbody>
</table>
### Table 1: SBAS requirements associated with EGNOS-enabled ADS-B based services

<table>
<thead>
<tr>
<th>Accuracy (NACv)</th>
<th>(NACv = 2)</th>
<th>(NACv = 2)</th>
<th>(NACv=1)NA</th>
<th>(NACv=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Note 1) Requirements have been derived from ADS-B APT for the accuracy, Multilateration standard (ED117) for availability and continuity and ED87 for velocity accuracy which have been converted into ADS-B requirements and then SBAS requirements.

(Note 2) Surveillance requirements have been derived from ED87 (version D and B) for accuracy and ED87 for velocity accuracy which have been converted into ADS-B requirements and then SBAS requirements. Experts expressed the need to increase vertical accuracy but it is not clear how it can be used. The value is derived from the ADS-B quantization.

(Note 3) Experts expressed need for vertical accuracy improvement but real use is not yet clear. The value is the minimum value from the Geometric Vertical Accuracy value defined in ADS-B MOPS.

An assessment of the performance of ADS-B data based on current GPS RAIM equipment (both theoretically using simulations and based on real reported positions) concluded that:

- Based on simulations, GPS RAIM augmented equipment with avionics operating in “SA Off mode” are not able to support the selected ADS-B operations. However, monitoring of real data indicates that aircraft (25% of DO-260B compliant aircraft) are capable to broadcast NACp 10 and NACp 11.

- Legacy SBAS equipment could provide the required accuracy in the whole EGNOS coverage area and/or at the required availability for Enhanced A-SMGCS and Alternative A-SMGCS operations requiring NACp 10.

- SURF-A is envisaged to be deployed with the current ADS-B performance (based on GPS RAIM equipment). However, SBAS could be beneficial to provide a better accuracy.

- DFMC SBAS could be required for SURF-IA to provide the required accuracy (in particular at small airports where requirements for accuracy are more stringent) or for Enhanced A-SMGCS and Alternative A-SMGCS operations requiring NACp 11.

#### 4.1.3 Safety risk analysis

A preliminary safety analysis has been done to assess the risk associated with the use of the same source of position information (based on EGNOS) for both navigation and surveillance in the European airspace.

The safety assessment considered a set of assumptions for the period considered, i.e. 2025 onwards, as follows:

- All aircraft are equipped with an alternative mean of navigation (in addition to GNSS-based navigation);
- Pilot reports the loss of RNP or RNAV capabilities to the controller;
- ADS-B is used as an additional surveillance means in High/Medium density airspace (i.e. ADS-B RAD application) and as a sole mean of surveillance in low-density airspace (i.e. ADS-B NRA application).
In the worst case, the SBAS system failures (i.e. integrity and continuity failures) could contribute to hazards of severity 2 in both radar and non-radar airspaces. However, the estimated associated likelihood would be very low and would be due to:

- **EGNOS failures:**
  - integrity failure with a position error greater than containment bound at integrity level (i.e. $10^{-7}$, as required in the European ADS-B mandate); the worst situation would be ramp error (slow drift);
  - continuity failure and the loss of horizontal position information (i.e. $10^{-5}$, which corresponds to SBAS continuity performance);
- **Radar unavailability ($10^{-4}$) for high density airspace or aircraft in proximity for low density airspace ($10^{-7}$);**
- **Ground ATC system failure.**

Moreover, technical and procedural mitigation means have been identified that would allow reducing the severity or the likelihood, including the ATC system (and the tracking function), the alternative navigation solution (i.e. A-PNT), the report of the loss of RNAV or RNP capability by the pilot to the controller and the controller coordination with pilot in case of failures for multiple aircraft.

Consequently, based on the assumptions and identified mitigation means and considering the EGNOS V3 performances, the safety risk associated with the use of EGNOS V3 performances, the safety risk associated with the use of the same source of position for navigation and surveillance would be acceptable and there should be no impact for the SBAS function in general, i.e. the SBAS system and the receiver which is already DAL B certified.

### 4.1.4 Service provision

The use of EGNOS to support ADS-B applications should not impact the current service provision scheme for the navigation service and the EGNOS Service provider will remain a “Navigation Service Provider”.

Moreover, considering the fact that the foreseen EGNOS V3 technical architecture required for the provision of a Surveillance service, based on ADS-B improved by EGNOS, should not change significantly compared to the current EGNOS architecture, there is no reason to have another EGNOS Service Provider dedicated to EGNOS-enabled ADS-B services. The EGNOS-enabled ADS-B based service will be provided by the ESP.

However, a new specific Service Level(s) (SL) of the EGNOS Safety of Life service (SoL) may be required for the provision of the Surveillance service, based on ADS-B improved by EGNOS.

From a surveillance service perspective, the EGNOS-enabled ADS-B based service could be embedded in ATS services provided by regular ANSPs or be provided by third-party dedicated organisation(s). In both cases, this would only affect the downstream organisations that could be involved in an ADS-B surveillance service provision.

### 4.1.5 Implementation timeline

The implementation of the new ADS-B operations will rely on the availability of a set of enablers, as follows.
**Service provision**

The EGNOS-enabled ADS-B based applications will not impact the service provision scheme from the ESP perspective.

The main activities for ESP should be limited to:

- Safety assessment of the new EGNOS service;
- Definition of specific Service Level(s) (SL) of the EGNOS Safety of Life service.

**Standardisation**

Standards per application defining the associated requirements will have to be delivered.

For A-SMGCS related applications, this may include:

- An upgrade of the existing A-SMGCS standards (e.g. ED-87) to take into account the additional surveillance layer or the provision of a new standard for Alternative A-SMGCS;
- An update of the standards for ADS-B Ground stations;
- An update of the standards for A-SMGCS data fusion and processing.

Update of ICAO documents may happen but this should be optional.

On the airborne side, this would include standardisation of the DFMC SBAS receiver, the publication of the EUROCAE/RTCA MOPS, and the publication of the associated E-TSO/TSO for equipment manufacturer and the update of CS-ACNS by EASA for aircraft manufacturer.

For SURF-IA, the provision of the EUROCAE standard (e.g. the Safety and Performance Requirement standard) and the update of the ASA (Aircraft Surveillance System) MOPS as well as the publication of the associated E-TSO will be required.

SURF-A is currently under development by the manufacturer without published standards.

**Regulation**

Since current European regulation encourages the use of A-SMGCS, a new regulation at EU level may be required for:

- The implementation of Enhanced A-SMGCS or Alternative A-SMGCS in secondary airports, similar to the existing PCP for major airports;
- The implementation of SURF-A/SURF-IA;

**Aircraft**

At the minimum, aircraft will have to be equipped with DFMC SBAS or legacy receiver. Due to the European ADS-B mandate, it is assumed that aircraft should be ADS-B equipped by 2020.

The main required activities are:

- Development and availability of DFMC equipment; in particular, the equipment will have to be certified or confirmed for surface operations, which is not the case today.
- Development and Availability of SURF-IA/SURF-A equipment;
- Aircraft certification with the new equipment (SBAS appropriate receiver and SURF-A/SURF-IA equipment);

**Ground Infrastructure**

For Enhanced and Alternative A-SMGCS, this will include:

- A possible upgrade of the ADS-B ground stations to be in line with new standards;
- The implementation of an alternative A-SMGCS or the upgrade of existing A-SMGCS (i.e. data fusion systems) to include additional surveillance data;

Considering these enablers, although they are not completely mature, there are no major blocking points in the feasibility of these applications.

The earliest dates of deployments would be as follows:

<table>
<thead>
<tr>
<th>Area</th>
<th>Initial date of operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced A-SMGCS</td>
<td>2029</td>
</tr>
<tr>
<td>Alternative A-SMGCS</td>
<td>2029</td>
</tr>
<tr>
<td>SURF-A</td>
<td>Planned for 2021; not a driver for EGNOS V3</td>
</tr>
<tr>
<td>SURF-IA</td>
<td>2029</td>
</tr>
</tbody>
</table>

**4.1.6 Cost Benefits Analysis**

The costs and benefits have been estimated for ANSP and Airspace users for the three segments: airports where A-SMGCS is already implemented, airports where A-SMGCS is not implemented and SURF-A/SURF-IA. Costs for the ESP would be associated to regulatory process and are not quantified.

The generic benefits associated with A-SMGCS solutions are:

- An increase in throughput and flight efficiency, as a results of the better planning of traffic flow on the airport surface; this increase in throughput and flight efficiency can be obtained both in good and low visibility conditions.
- A reduction in delays for the airspace users during low visibility conditions
- An increase in safety, as a results of the provision of alerts about conflicting situations. The benefits are estimated not on the incident itself but on its consequences on the continuity of surface operations.

**For airports where A-SMGCS is already implemented and where “Enhanced A-SMGCS” could be implemented:**

49 airports could benefit from Enhanced A-SMGCS. These are mainly large/very large airports (more than 150000 movements per year) as well as some medium airports.

**For Airspace users**

Possible benefits are expected based on the optimisation of the taxitime and it would be highly beneficial for very large and large airports. Additional benefits based on the monetisation of reduction of delays for airspace users during low visibility should be obtained but were not quantified.
In term of costs, no additional ADS-B equipment costs would be required for users already equipped to comply with the European ADS-B mandate. The only cost would be for the SBAS receiver.

For ANSP

An increase in throughput on the airport surface should be possible due to the optimisation resulting from the Enhanced A-SMGCS. However, this was not monetised. Additional safety benefits should be obtained but without a better knowledge of the improvements (e.g. in term of alerts) these were not quantified.

Investment costs for the ANSP will only be limited to an update of the current infrastructure of A-SMGCS data integration/fusion to receive ADS-B data, the multilateration infrastructure being assumed to be compliant with ADS-B data.

For airports where A-SMGCS is not implemented and where “Alternative A-SMGCS” could be implemented:

At first 86 small and medium airports could benefit from “Alternative A-SMGCS” but it be could deployed at a larger scale in Europe.

For Airspace users

Benefits associated with an optimisation of the taxi-time can be obtained but are not relevant.

The main expected benefits are safety benefits associated with a reduction of delay and cancelation of flights that would result from the taxiway or runway unavailability because of incident. Additional benefits based on the monetisation of reduction of delays for airspace users during low visibility should also be expected but were not quantified.

In term of costs, no additional ADS-B equipment costs are required due to European ADS-B mandate. The only cost would be for the SBAS receiver.

For ANSP

An increase in throughput on the airport surface should be possible due to an improvement of the airport throughput during low visibility optimisation resulting from the Alternative A-SMGCS. However, this was not monetised.

The main benefits would be safety benefits associated with continuity of the revenue that could result from a decrease of the impact on incident on the continuity of airport activities.

Investment costs for the ANSP will include the deployment of the ADS-B infrastructure, the surveillance sensors for non-equipped aircraft and the A-SMGCS system, all of which may offset the benefits for such airports.

For SURF-A and SURF-IA:

These two applications provide on-board safety nets to pilot and increase safety on airport surface whether the airports are equipped with A-SMGCS or not. Nevertheless, the quantification of the benefits for both Airspace Users and ANSP associated with SURF-A and SURF-IA is difficult to estimate at airports equipped with “Enhanced or Alternative” A-SMGCS which provide safety net to controllers. Genuine benefits could be at small airports not equipped with A-SMGCS.

The associate costs would be related to the airborne equipment for the provision of alerts and the SBAS receiver.

An overview of the estimated quantified costs and benefits is provided in Table 2.
<table>
<thead>
<tr>
<th>Services per segment</th>
<th>ANSP</th>
<th>AU</th>
<th>ESP</th>
<th>ANSP</th>
<th>AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced A-SMGCS at airports already equipped with A-SMGCS</td>
<td>200K€ (update of A-SMGCS fusion process)</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Not quantified</td>
<td>Taxitime benefits: 70K€ to 2M€ (medium to very large airports)</td>
</tr>
<tr>
<td>Alternative A-SMGCS at airports not equipped with A-SMGCS</td>
<td>2,5M€ (Ground infrastructure, data fusion process, vehicles)</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Safety benefits* 1K€ to 50K€ (small to medium airports)</td>
<td>Taxitime benefits: 14K€ to 250K€ (small to medium airports) Safety benefits*: 20K€ to 7M€ (small to medium airports)</td>
</tr>
<tr>
<td>SURF-A/SURF-IA</td>
<td>NA</td>
<td>100K€ per aircraft + ADS-B IN equipment (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Not quantified</td>
<td>Not quantified</td>
</tr>
</tbody>
</table>

Table 2: Costs and Benefits associated with EGNOS-enabled ADS-B based services
4.2 EGNOS Vertical Reference Service

4.2.1 Identification of future new service

List of services
To determine the future services that may benefit from DFMC SBAS, an analysis of the planned CNS/ATM services to be deployed in the timeframe defined by the study has been undertaken with a review of existing R&D activities (including ICAO GANP and SESAR projects). Having determined the services that fall under this category, the next step was to analyse the services to understand where the operation gaps in the future CNS/ATM services are, therefore providing the basis for a set of new proposed future services.

The results of this analysis have led to the following proposals for future services:

- Terrestrial timing networks
- Very Low Level trajectory based operation in urban areas for RPAS
- Geofencing
- Use of EGNOS as a new altitude reference system
- “Detect and avoid” like service for GA
- e-Identification services
- U-space proposed solutions applied to manned aviation

Stakeholder requirements
The next step was to consult the ATM stakeholder’s to assess their interest in the new services.

The stakeholders were asked to provide their view on how each of the proposed new services will need to be performing from an availability, accuracy, continuity and integrity point of view to satisfy their future operational needs. The results showed a need for increased performance of EGNOS if it were to support the proposed future services as follows:
<table>
<thead>
<tr>
<th>Service</th>
<th>Accuracy</th>
<th>Availability</th>
<th>Continuity</th>
<th>Integrity (Note 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral</td>
<td>Vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrestrial timing networks</td>
<td>N/A (57.14%)</td>
<td>N/A (57.14%)</td>
<td>0.99999 (42.86%)</td>
<td>=&gt;99%/h (57.14%)</td>
</tr>
<tr>
<td>Very Low Level trajectory-based operation in urban areas for RPAS</td>
<td>&lt;5m (28.57%)</td>
<td>&lt;5m (42.86%)</td>
<td>0.99999 (28.57%)</td>
<td>=&gt;99%/h (71.43%)</td>
</tr>
<tr>
<td>Geofencing</td>
<td>&lt;15m (42.86%)</td>
<td>&lt;30m (28.57%)</td>
<td>0.999 (57.14%)</td>
<td>=&gt;95%/h (71.43%)</td>
</tr>
<tr>
<td>Use of GNSS as a new altitude reference system</td>
<td>&lt;1m (42.86%)</td>
<td>&lt;5m (42.86%)</td>
<td>0.99999 (57.14%)</td>
<td>=&gt;99%/h (85.71%)</td>
</tr>
<tr>
<td>“Detect and avoid” like service for GA</td>
<td>&lt;15m (28.57%)</td>
<td>&lt;10m (57.14%)</td>
<td>0.99999 (28.57%)</td>
<td>=&gt;95%/h (57.14%)</td>
</tr>
<tr>
<td>U-space capabilities extended to manned aviation</td>
<td>N/A (42.86%)</td>
<td>4m to 20m</td>
<td>N/A (42.86%)</td>
<td>N/A (42.86%)</td>
</tr>
</tbody>
</table>

Note 1: The percentage values represent the percentage of people who support the requirements.

Note 2: It corresponds to the importance of the integrity for the listed services, which can be critical, essential or required.

**Future service dependency and down selection**

Finally, the questionnaire aimed to identify which of the future proposed services is the most promising and most appealing to the stakeholders. The analysis took into account the relevance of each service for the future ATM environment, the number of stakeholders that could benefit from the deployment of the service as well as the deployment and governance of the service.

**Selected service**

Based on the feedback obtained, it was decided to select the altitude service, it was agreed to select the service “Use of GNSS as a new altitude reference system. This service is referred as the new vertical reference service from this point forward.

The new service proposes the use of EGNOS as a single global reference system for altitude. This would allow the use of the same setting across the entire airspace where an aircraft operates. The main benefit would be that the indicated altitude will no longer be affected by meteorological and environmental conditions. Additionally, this solution can be used for both manned and unmanned aviation as well as for any future entrants into the ATM environment.

A high resolution Digital Terrain Elevation Data (DTED) database could be created to support the implementation of this service. There is an implicit requirement also that a high resolution DTED is deployed as part of the service. Another solution would be to use Earth observation (EO) assets to support changing digital maps.

*Note: The provision of timing services for communications systems was finally not investigated as part WP1.2, as initially envisaged. This “new vertical reference service” has been selected following the stakeholders’ consultation.*
The SBAS requirements associated with the “new vertical reference service” are summarised in Table 3. These requirements have been obtained from the stakeholders’ consultations in which stakeholder selected among a set of proposed values.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Vertical reference service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal accuracy 95%</td>
<td>&lt;1m</td>
</tr>
<tr>
<td>Vertical accuracy 95%</td>
<td>&lt;5m</td>
</tr>
<tr>
<td>Integrity risk</td>
<td>10⁻⁹</td>
</tr>
<tr>
<td>Time to alert (TTA)</td>
<td>2s to 5s</td>
</tr>
<tr>
<td>Horizontal Alert Level (HAL)</td>
<td>10m to 30m</td>
</tr>
<tr>
<td>Vertical Alert Level (VAL)</td>
<td>2.5m to 7.5m</td>
</tr>
<tr>
<td>Continuity risk</td>
<td>99%/h</td>
</tr>
<tr>
<td>Availability</td>
<td>0.99999</td>
</tr>
<tr>
<td>Horizontal Velocity Accuracy (NACv)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 3: SBAS requirements associated with EGNOS Vertical Reference service

4.2.2 Regulatory analysis

Part of the analysis was to identify the regulatory requirements that apply to the new vertical referencing service from a service provision, safety oversight, including safety performance monitoring, and interoperability point of view. The analysis looked at the European regulations that concern the elements listed above.

The regulatory analysis has shown that the new vertical reference service fits in well within the regulatory environment and processes required for a new pan-European service to be brought into the market. However, an analysis of the global standards at ICAO Level is also required.

The introduction of a new altitude reference system would require a fundamental change for the ICAO Annexes as they all clearly specify that altitudes and heights need to be measured with reference to atmospheric pressure translated to heights and elevation with respect to Mean Sea Level. This would mean a complete change in the way of measuring all points in the vertical axis and with it all the procedures and ATM related publications.

In order to make such a big change in ICAO SARPs’, it would take an effort at global level to first endorse it and then support it through national, regional and global plans, for the roll out of the new operating concept. This change would go through ICAO’s process of making amendments and which would be completed through the ICAO Air Navigation Conferences.

The change required to allow for the implementation of the new vertical reference service is more related to how Flight Levels and all altitude related information is derived. The definition of the Flight Level will not be changed. Therefore, in the case of Flight Level, additional note(s) will be added to the ICAO SARPs to define how the geodetic calculation of altitude will be used to identify the aircraft’s flight level. Conversion tables will be used to relate geodetic altitudes to barometric ones and these will be embedded in the aircraft’s on-board equipment. This change needs to be permeated through all of the ICAO Annexes.
4.2.3 Service implementation

From an operational stand point, there are two sides to the change required to accommodate the implementation of the new vertical reference service. One of them is relating to the technical side of air transport operations requiring the aircraft to be equipped with new avionics, which can be referred to as “vertical reference box” providing aircraft systems with vertical position information via the service rather than the existing static port and barometric pressure, and the ATM systems to be updated with the new data feed for vertical position. The other one is related to the concept of operations, which even though is foreseen to be updated in a transparent way without any change to the look and feel for the ATCOs and the pilots, the concept of operations will need to be updated to enable the mixed mode operations environment in the first stages (until the standards and specifications have been fully matured and published) and then to accommodate the complete paradigm switch from a ground based reference frame to a space-based one.

The implementation of the service requires different levels of equipage from both airborne and ground perspectives dependent on whether this deployment is in oceanic airspace or continental airspace (including en-route, TMA, approach and departure and Very Low Level (VLL) airspace).

In the future it is envisaged that the service will be deployed globally as an ICAO recognised service – albeit only within SBAS coverage volumes. While this approach will clearly have an impact on the operations if deployed in one go, the best way to go forward may be a step-wise approach which would see an incremental transition targeting those current operations already benefiting from geodetic altitudes – e.g. LPV approaches – extending later to cover all operations.

The incremental approach would provide immediate benefits since the deployment would be usable provided there is a SW upgrade in the current avionics and therefore deliver a quick win when extended to the whole instrument approach in the TMA. The implementation of the service in the TMA will bring some fuel savings and will contribute to the reduction of environmental and noise impacts over the surrounding communities through more stable, higher and vertically repeatable Continuous Descending Operations (CDO) than today.

During the first phase of the service being extended to all operations, between IOC and FOC, two-way conversion tables will be used to allow airspace users to use both methods for altitude calculation: barometric and geodetic. This phase will see ANPSs running mixed mode of operations where they cater for both barometric and geodetic users facilitated through system upgrades. The conversion tables will therefore play a key role ensuring the data provided by the two systems is consistent.

The difficulty in implementing the new service in the en-route phase is that currently the barometric setting used for the altitude computation is different depending on the area where the aircraft is flying. The issue comes from flights over oceanic areas where there is no way of defining a local barometric pressure and therefore FLs are determined relative to a standard pressure setting of 1013.2 mb. Transition to a vertical reference service at a global level could require the development of a new data model which can convert the barometric altitude over the ocean into a geodetic altitude.

This change will clearly impact the way information for vertical navigation is provided in ATM related publications. The analysis has shown that the development focus will be needed in standardisation to push acceptance of the new solution at global level. This will be done through ICAO but, considering the relatively low pace of solution implementation in aviation, it can take a long time to have everything in place for the global implementation. The proposed approach for the roll-out of the service is to
have a transition period during which conversion tables having forward and backward compatibility with the barometric system will support ANSPs to cope with a mixed fleet.

It is expected that that the Barometric system will be maintained as a back-up/contingency system until the required redundancy can be achieved using the Multi Frequency Multi Constellation operations or until a different system (e.g. ARAIM) can provide this function.

4.2.4 Service provider analysis

The evaluation of the service provision also looked into the best option for the service provider of the new vertical reference service. The two options proposed were the following:

- Provision of service through the EGNOS Service Provider (ESP)
- Provision of service through a new service provider

Setting up a new service provider would require a lot more time to develop all the required documentation and processes for certification, safety oversight and monitoring as well as the ones for the service and system interoperability than updating ESP’s current certificate. The latter would only need to provide sufficient evidence to EASA that the functional change will not have a negative impact on the performance of the current navigation service provision. Therefore, the introduction of the new vertical reference service will not require a change in the type of certification that ESP holds currently.

Consequently, the most suitable option would be for ESP to update their service provider certificate therefore providing their service through the same channels as the other navigation service(s). It will still require ESP to complete a safety assessment for the functional change but it will not require them to set up new processes for safety oversight and safety performance monitoring.

4.2.5 Implementation timeline

The required time for each phase is detailed below and illustrated further down in Figure 1:

- It is estimated that by 2025, the complete development of the service, including the definition of the CONOPS, has been completed.
- Standardisation for both ground and airborne segments is estimated to start in 2025, when the service has been completely defined, and will be completed in 7 years.
- Update of the SBAS ground segment, illustrated as “EGNOS V3.x Vertical Reference Update in Figure 1, will start in 2027 and will run for the full lifetime of the service;
- Certification and development of the avionic to be installed on-board the aircraft will start in 2030 and will be completed by 2035.
- Update of the ground segment, illustrated below as “Update of ATM Systems”, will start in 2035, once the Standardization has been completed;
- Equipage of global aircraft fleet is planned to start in 2035
  - The GA forward fit and retrofit is estimated to be completed by 2055;
  - The CA forward fit is estimated to start in 2035, one the Certification phase has been completed, and to be completed by 2050;
The RPAS are considered to be updated with the required capabilities once the Standardization phase has been completed.

- The Transition period is defined from the IOC to the FOC during which the Mixed Mode of Operations will be in place. At IOC, only a limited number of aircraft will be able to use the reduced vertical separation minima therefore clear procedures will be used to separate these from the non-equipped aircraft. Once all the aircraft have been equipped, the new vertical separation minima of 700ft could be implemented all around the globe.

Due the approach for maintaining the look and feel for both air crew and ATCOs there will be some training required however the amount of training required will only be identified once the CONOPS has been clearly defined. Training should be required for the implementation of the reduction of vertical separation minima.

![Vertical reference service timeline](image)

**Figure 1: Vertical reference service timeline**

### 4.2.6 Cost benefits analysis

#### Costs

The costs have been estimated for the end-users of the services, i.e. the Airspace Users and the ANSPs, taking into a series of assumptions.

**Airspace Users**

For Commercial Aviation users, the assumption that only a forward fit approach will be used means that these users will receive the vertical reference conversion table as part of the standard configuration of the aircraft.

Forward fit is assumed to avoid the costs associated with retrofit. Perhaps there would be some costs from database updates to provide the conversion tables during the transition period. However, the datalink will already exist, and not cost anything. If this were to be through datatables, this should also be automated. So it is assumed that this is part of the service, and does not result in any additional costs for CA community and any other AU.

For General Aviation users, the underlining assumption is that the cost of the vertical reference box will be equivalent to the cost of the static port box which is replaced as part of the forward fit phase in all new aircraft being manufactured from 2035 onwards. Moreover, there is an assumption that the reliability will be such that for
GA there will not need to be a backup. The move for GA is for navigation to be fully dependent on GNSS (and so including the vertical).

For the retrofit stage of GA, an assumption has been made that a one-off cost of 1,500 EUR would be incurred by aircraft being retrofitted with the vertical reference box. However as only 44% of the GA aircraft would be retrofitted (the rest being replaced with new aircraft) it would allow reducing the overall required investment.

For RPAS, as these can be upgraded/equipped in a shorter timeframe than any other airspace user, it has been considered that these should already be capable of using the service as part of their existing capabilities at that time. Therefore, no additional costs are anticipated for the RPAS community.

**ANSPs**

The costs associated to the use of the new vertical reference service are mainly related to the update of the ATM systems. This being required for the ATM systems to allow the new data feed to be processed and used in operations. In the case of the new vertical reference service, the system update would need to cater for the conversion tables that would allow the ANSPs to accommodate the Mixed Mode of operations during the transition period.

Additionally, there are cost related to the redesign of the airspace, to implement the new routes at 700ft vertical separation. The costs of airspace redesign is different from country to country and should not be neglected but it has not been quantified within the study.

**Benefits**

In terms of benefits, a number of both quantifiable and non-quantifiable benefits have been identified for the two stakeholders: Airspace Users and ANSPs. In order to analyse the benefits, the service provision has been split into three different market segments as follows.

A split between oceanic and continental benefits has been done based on the assumption that only 11% of the total traffic is oceanic. All the amounts have been discounted to 2019 and they represent the total savings for that year: 2037 (IOC) and 2057 (FOC).

<table>
<thead>
<tr>
<th>Market segment</th>
<th>Stakeholders Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanic airspace</td>
<td>Commercial Aviation</td>
</tr>
<tr>
<td></td>
<td>ANSPs</td>
</tr>
<tr>
<td>Continental airspace</td>
<td>Commercial Aviation</td>
</tr>
<tr>
<td></td>
<td>General Aviation</td>
</tr>
<tr>
<td></td>
<td>Rotorcraft operators</td>
</tr>
<tr>
<td></td>
<td>ANSPs</td>
</tr>
<tr>
<td>Very low level airspace</td>
<td>RPAS</td>
</tr>
<tr>
<td></td>
<td>ANSPs</td>
</tr>
</tbody>
</table>

**Airspace Users**

The following benefits have been identified:

For Commercial Aviation in Oceanic airspace:

- Increases safety by providing a service with increased accuracy for all AUs.
• Reduces the vertical separation of aircraft therefore allowing all flights to be closer to their optimal level enabling an improved fuel consumption.

For Commercial Aviation, General Aviation and Rotorcraft operators in the Continental airspace:
• Increases safety by providing a service with increased accuracy for all AUs.
• Reduces the pilots workload by removing the switching and communication of the atmospheric pressure reference.
• Reduces the vertical separation of aircraft therefore allowing all flights to be closer to their optimal level enabling an improved fuel consumption.

For RPAS operators in the Very Low Level airspace:
• Increases safety of operations and social safety by providing a service with increased accuracy and availability for all RPAS operations.

ANSPs
The following benefits have been identified

In Oceanic airspace:
• Increases airspace capacity by reducing the vertical separation between the aircraft.
• Fosters air traffic growth providing increased revenue for ANSPs.

In Continental airspace:
• Reduces the ATCOs workload by removing the switching and communication of the atmospheric pressure reference.
• Increases airspace capacity by reducing the vertical separation between the aircraft.
• Barometric sensors will no longer be required at airports.

In Very Low Level airspace:
• Enables the development and deployment of UTM services.
• Enables the integration between ATM and UTM systems.

The move towards the new service should be mainly a political decision and benefits are a practical reason to support this decision. Beyond that, automation and increased digitalisation in ATM and U-Space could reasonably be expected to lead to a situation where a common vertical reference system is used. This should be GNSS as the only global solution. This would need to be supported by all users because this could solve not just some of the cost issues, but also the safety and integrity issues of moving to a digital based solution.”

The quantified benefits and costs are provided in the Table 4
<table>
<thead>
<tr>
<th>Services per segment</th>
<th>ANSP</th>
<th>AU</th>
<th>ESP</th>
<th>ANSP</th>
<th>AU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical Reference Service in Oceanic area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2037</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500KE per ANSP (ATM system upgrade for new data feed)</td>
<td></td>
<td></td>
<td></td>
<td>5,9M€</td>
<td>680K€</td>
</tr>
<tr>
<td>2057</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA: 1,5KE per aircraft (for retrofit)</td>
<td>NA</td>
<td></td>
<td></td>
<td>3,8M€</td>
<td>23,3M€</td>
</tr>
<tr>
<td>No additional costs for forward fit for either of the AUs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vertical Reference Service in continental area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2037</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500KE per ANSP (ATM system upgrade for new data feed)</td>
<td></td>
<td></td>
<td></td>
<td>8M€</td>
<td>790K€</td>
</tr>
<tr>
<td>2057</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA: 1,5KE per aircraft (for retrofit)</td>
<td>NA</td>
<td></td>
<td></td>
<td>5M€</td>
<td>157M€</td>
</tr>
<tr>
<td>No additional costs for forward fit for either of the AUs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Costs and Benefits associated with EGNOS Vertical Reference Service
4.3 SBAS Authentication service

4.3.1 Background

Until recently, spoofing was considered as a potential threat that has never been experienced by GNSS users. This is not true anymore and several spoofing episodes have recently been reported by GNSS users.

To mitigate the associated effects, authentication can be seen as a way to detect spoofing and to inform aircrew that SBAS cannot be trusted.

Solutions for the authentication of SBAS signals can rely on many approaches but all come to the insertion of a cryptographic signature in the SBAS message. This cryptographic signature is generated by the ground segment by using secret cryptographic root material and the verification of the signature is performed by the user by using public cryptographic material known as a public key.

4.3.2 Key Management proposed Approach

The transmission of the public cryptographic material is proposed to be performed through the signal in space rather than through any other mean. The motivation for this is given in the following paragraphs.

In the event of a planned update of the public cryptographic material, the update could be performed through a data link connection. Nevertheless, aircrafts do not have permanent access to secure data links and thus a key update in the event of compromise might take a long time; allowing for the attack to go undetected until the next time the aircraft establishes a connection to a secure data link.

Furthermore, the use of a data link to update the cryptographic material would require an additional interface between onboard communication equipment and the SBAS airborne receiver introducing an inter system dependency impacting the overall safety case which is not desirable.

For the same reasons as the ones exposed in above, it is proposed that the authentication of the SBAS message is performed by the onboard SBAS receiver itself without relying on external additional equipment for doing so.

Based on the above, the management of the public cryptographic material is proposed to be performed by the use of a Public Key Infrastructure (PKI).

In this scheme, an aeronautical authority (outside of the SBAS service provider’s control) is responsible for signing the public cryptographic material generated by the SBAS provider. It does this by using secret cryptographic material (identified as B material on Figure 2 below) and makes available public cryptographic material to the aeronautical community in order for them to verify elements authenticated by the aeronautical authority.

The public cryptographic material used to verify signatures issued by the aeronautical authority is loaded in the onboard avionics at the factory and updated, if need be, under a process to be defined (e.g. through operational maintenance). Validity of this cryptographic material can be long (e.g. 10 years).

All SBAS messages transmitted by the SBAS service provider are then signed using the SBAS provider cryptographic secret key (identified as Ai on Figure 2 below).

In periods that are outside of SBAS provider cryptographic material renewal, the SBAS provider periodically broadcasts the currently valid cryptographic material.
signed by the aeronautical authority (identified respectively as Key Packet Ai and Key Packet Ai+1 on Figure 2 below).

Upon reception of the public cryptographic material for the authentication of the SBAS messages, the airborne receivers authenticate this material using the aeronautical authority cryptographic material and stores it in non-volatile memory (Authenticates Key packet Ai with key B when using the nomenclature of Figure 2 below).

In periods where the SBAS provider cryptographic material is being renewed, a higher frequency of transmission is used to broadcast the new cryptographic material signed by the aeronautical authority along with a time of applicability for the new material.

In the event that the SBAS provider cryptographic material has been compromised, a higher frequency of transmission is used for the new cryptographic material signed by the aeronautical authority along with a revocation for the previous cryptographic material.

![Figure 2: Illustration of the authentication approach](image)

4.3.3 Business model

Two options have been envisaged for the delivery of the authentication service:

- Option 1: The authentication service is provided by the same service provider as the EGNOS system and transmitted on the same data exchange channel as the one used for the exchange of augmentation information.
- Option 2: A separate service provider is responsible for the provision of the authentication service. The authentication service is provided in coordination with the ESP.

The following Figure 3 provides an overview of the role model, including the actors, systems and their relationships.
Assuming that the authentication data is transmitted in the SBAS SiS, the same operator for both SBAS and authentication is preferred:

- Introducing new service providers would imply administrative and technical (interfaces) complexity, including a new point of attention for the overall system security.
- Each service provider would share the same bandwidth-limited communication channel for providing the service which could lead to capacity issues.

Choosing the SBAS SiS as communication link highly constraints the business model and Service Access Policy (SAP). Indeed, while it ensures that every EGNOS user has access to authentication data, it also simplifies Service Access Policy as it is implemented by the distribution of public keys that allows the users to verify the authentication data contained in the SiS.

### 4.3.4 Implementation road map

The time required for the implementation and deployment of the SBAS authentication service to aviation in Europe is defined by three main contributors:

1. Standardization;
2. System development;
3. User receiver development and qualification.

Additionally, the following impacts on the system have been taken into account for the implementation roadmap:

- New constraints on NLES site selection to have a secured area and need for NLES updates to take new interfaces into account;
- New developments on:
  - Hardware Security Module (HSM) to compute the authentication signature;
  - Key Distribution Infrastructure (KDI) to generate public and private keys;
  - Black Box Key Management Equipment (BBKME) as the key dissemination mean;
In term of deployment, updating the ground segment would take at least 3 years, ignoring standard and receiver development constraints.

The proposed roadmap is as follows.

4.3.5 Cost evaluation

The costs for the deployment of an SBAS authentication service include:

**System related costs**
- NLES update;
- RIMS A or B update;
- KDI development;
- BBKME development;
- Development of two system releases;
- Development of a Test User Receiver (TUR)

Optionally, a new RIMS dedicated to authentication signatures verification could be developed and deployed in addition of existing RIMS.

**User Receiver related costs**

Assuming that the authentication data verification is performed at receiver level, the following updates are required:
- Update of the navigation data processing module. The update is imposed by the ICD update, so that the receiver knows which bits will be part of the authentication load.
- Creation of a cryptographic module to verify the authenticity of the navigation data, and new mechanism for declaring the PVT solution not authenticated.
- Development of a certified receiver; the costs will depend on the number of requirements and will be funded by manufacturer which will adjust receiver’s recurring price to refund the investment.
4.4 Potential EGNOS approach services beyond CAT I

4.4.1 Identification of potential new EGNOS approach services beyond CAT I

Two approach services have been selected for analysis, namely SA CAT I and CAT II: These approach services beyond CAT I already exist in current or future European regulation, and are supported by other navigation systems different to SBAS.

- **Special Authorisation (SA) CAT I operations:**
  - SA CAT I approaches are introduced in the EASA NPA 2018-06 (RMT.0379) as an operational credit to extend the instrument segment of a CAT I approach to allow CAT I operations down to a DH of 150 ft, subject to holding specific approval from the competent authority.
  - The SA CAT I defined in EASA NPA 2018-06 is intended to be supported by ILS CAT I or equivalent.
  - SA CAT I operations are also defined in other regions of the world like USA and Australia.
  - A specific certification is required for SA CAT I operations.
  - There are specific requirements for on-board equipment (for example, use of autoland or other equipment like Head Up Display).
  - SA CAT I requires CAT I runways with specific requirements. For runways with irregular pre-threshold terrain or other foreseeable or known deficiencies, each aircraft type/runway combination should be verified by operations in CAT I or better conditions, prior to commencing SA CAT I.

- **CAT II operations:**
  - Equivalent to current CAT II operations.

4.4.2 Operational needs in Europe for potential SBAS approach services with minima beyond CAT I

Statistics indicate that European airports that have implemented Low Visibility Procedures (LVP) operate in low visibility conditions approximately between 15 and 30 days per year, during a few hours per impacted day, for a total of between 15 and 170 hours per year. Nevertheless, the probability of low visibility meteorological conditions depends on each airport and there can be important differences between airports.

Although the period of time an airport is under low visibility conditions may be short, the consequences of stopping the arrivals because of low visibility conditions even for a short period are usually important (aircrafts holding or diverted). In general, ANSPs have expressed interest in the possibility of SBAS-based services with minima lower than CAT I, as it would allow improving the accessibility to airports in lower visibility conditions. The main feedback from ANSPs needs is:

- At airports currently not equipped with CAT II/III operations:
  - There is an special interest in developing SBAS operations with minima lower than CAT I using CAT I aerodrome infrastructure, so that additional investment on aerodrome infrastructure is not required. These operations would contribute to improve the access to the airport in low visibility conditions.
  - The costs of aerodrome/runway upgrade from CAT I to CAT II/III are high, even if a ground navaid (ILS) is not required. Therefore, if the new SBAS operations would require CAT II runways, the benefits from the new operation may not compensate the infrastructure investment.

- At airports already equipped with CAT II/III operations:
In general, airports with an operational need of CAT II or CAT III approaches already have ILS CAT II/III (or equivalent).

- SBAS approaches beyond CAT I would be mainly used as backup of ILS procedures or as an alternative during ILS outages/maintenance.

- Rationalisation of ILS CAT II stations by the use of a potential SBAS CAT II procedure is not likely to occur, at least during the first years these SBAS operations would be available, because ILS CAT II/III stations are seen as necessary equipment linked to an operational need. Rationalisation may occur after a few years and if an important percentage of the fleet is capable to fly the new SBAS procedure. Moreover, some ANSPs always equip a runway with an ILS CAT III whenever an approach below CAT I is needed (depending on financial resources).

Other topics:
- If SBAS approaches beyond CAT I are developed, it would be interesting to analyse if they could overcome some limitations of current ILS CAT II operations, like the restrictions with steep Vertical Path Angles (VPA).
- Business Aviation interest depends on the requirements for operators (ex.: CAT II authorization initially required by FAA for operators to fly SA CAT I might be relaxed).

### 4.4.3 EGNOS performance requirements to potentially support SA CAT I and CAT II

#### SA CAT I operations

SA CAT I is currently defined to be supported by ILS stations compliant with ILS CAT I performance requirements. EGNOS V3 CAT I requirements with VAL 10 m are equivalent to ILS CAT I requirements, and therefore it is likely to be able to support SA CAT I operations.

Additionally, an analytical assessment of the aircraft trajectory during the final approach segment of a SBAS approach with DH 150 ft and VAL 10 m shows that the ILS CAT II Obstacle Clearance Surface (OCS) is respected. This Egis theoretical analysis for SBAS SA CAT I and CAT II provides similar than those for LPV 200. Consequently, EGNOS V3 target performance requirements with VAL 10 m are likely to support SA CAT I operations, by equivalency with ILS CAT I performance.

This should be validated with real data once EGNOS V3 (in a dual frequency multi constellation configuration) is operational (and transmit the DFMC SBAS service signal supporting VAL 10m).

#### CAT II operations

SBAS performance requirements to support CAT II operations are not defined yet. A direct translation of ILS CAT II performance requirements into SBAS CAT II requirements would result in excessively stringent requirements for some of the parameters. E.g. very low availability obtained with simulations and some ILS CAT II requirements cannot be met with SBAS, like TTA 2 seconds.

Consequently, the derivation of SBAS requirements to support CAT II need to consider the characteristics of the SBAS system and its integration in the aircraft with other on-board equipment. For example, the SESAR project AAL2 aims at demonstrating the feasibility of performing CAT II operations using GBAS GAST C ground and on-board equipment.

The SBAS SA CAT I and SBAS CAT II requirements are listed in Table 5.
<table>
<thead>
<tr>
<th>Operations Indicators</th>
<th>EGNOS V3 CAT I performance specifications</th>
<th>SA CAT I (Note 1)</th>
<th>CAT II (Note 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal accuracy 95%</strong></td>
<td>16 m (current commitment is 3 m)</td>
<td>15.4 m (Note 2)</td>
<td>6.9 m (Note 4)</td>
</tr>
<tr>
<td><strong>Vertical accuracy 95%</strong></td>
<td>4 m</td>
<td>3.8 m (Note 2)</td>
<td>2 m (Note 4)</td>
</tr>
<tr>
<td><strong>Integrity risk</strong></td>
<td>2x10^{-7} / 150s</td>
<td>2x10^{-7} in any one landing</td>
<td>10^{-9} in any one landing</td>
</tr>
<tr>
<td><strong>Time to alert (TTA)</strong></td>
<td>6 s</td>
<td>6 s</td>
<td>2 s (recommended 1 s)</td>
</tr>
<tr>
<td><strong>Horizontal Alert Level (HAL)</strong></td>
<td>40 m</td>
<td>38.5 m</td>
<td>21 m</td>
</tr>
<tr>
<td><strong>Vertical Alert Level (VAL)</strong></td>
<td>10 m</td>
<td>9.5 m</td>
<td>6.1 m</td>
</tr>
<tr>
<td><strong>Continuity risk</strong></td>
<td>8 x 10^{-6} /15 s 10^{-5} (up to NPA)</td>
<td>8 x 10^{-6} in any period of 15 s</td>
<td>4x10^{-6} per 15 s</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>99%</td>
<td>99% to 99.999%</td>
<td>99% to 99.999%</td>
</tr>
<tr>
<td><strong>Horizontal Velocity Accuracy (NACv)</strong></td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 5: SBAS SA CAT I and SBAS CAT II requirements

(Note 1) Egis has obtained:
- the SA CAT I horizontal and vertical 95% accuracy requirements by linearization of ILS CAT I accuracy performance at a decision height of 150 ft, in a similar way as they were derived for SBAS CAT I at a decision height of 200 ft.
- the HAL and VAL (5σ value) by multiplying the corresponding accuracy requirement (2σ value) by 2.5, as described in RTCA DO-255A.

The integrity and continuity risk requirements correspond to the requirements for ILS stations of Level 2, targeted by EASA as the navigation mean to support ILS SA CAT I.

The TTA requirement corresponds to the one for ILS CAT I.

(Note 2) Egis has obtained the SA CAT I accuracy requirements by linearization of ILS CAT I performance at a DH of 150 ft, and the HAL/VAL have been derived scaling the accuracy by 2.5. This is one of the methods used to derive SBAS CAT I requirements (with a DH of 200 ft instead of 150 ft).

The requirements obtained with this method are slightly more stringent than the performances targeted by EGNOS V3, although this difference is small (0.2 m for the vertical accuracy and 0.6 m for the horizontal accuracy). Nevertheless, the theoretical analysis of the final approach trajectory presented in deliverable D310, similar to the analysis done at ICAO to justify the VAL of 35 m for LPV-200, shows that the final segment trajectory with a VAL of 10 m does not penetrate the ILS CAT I OCS with a DH of 150 ft, which indicates that the VAL of 9.5 m could be relaxed to 10 m. In the case of LPV-200, the justification of the VAL of 35 m was also supported by flight tests.
The requirements obtained through other methods may be slightly different; for example, an aircraft manufacturer has identified HAL of 40 m and VAL of 10 m as acceptable values to potentially support SBAS CAT II autoland operations, and MASPS LAAS RTCA identifies a VAL of 10 m and a HAL of 17 m for GBAS CAT II/III operations.

(Note 3) The presented CAT II requirements are based on equivalency of ILS CAT II requirements for information purposes only. It is recommended to derive SBAS CAT I requirements considering SBAS characteristics and its integration within the aircraft.

(Note 4) Egis has derived:
- the CAT II accuracy requirements by linearization of ILS CAT II performance at a DH of 100 ft (see MASPS LAAS).
- the CAT II HAL and VAL requirements by scaling the 95% accuracy (2σ value) by 3.05 to get a 6.1σ value (which corresponds to the 10e-9 integrity risk).

4.4.4 Safety analysis

The analysis of the functional level of safety that can be supported by SBAS approaches using DFMC SBAS receivers certified DAL-B has been made via the use of existing fault trees defined for SBAS SA CAT I and SBAS CAT II operations.

**SBAS SA CAT I**

SA CAT I operations are CAT I operations with operational credits, that is, SA CAT I are considered CAT I operations. The SBAS CAT I fault tree has been applied to SBAS SA CAT I, as follows.

- SBAS SA CAT I is based on a navigation system with ILS CAT I performance, and aircrafts and operators certified and approved SA CAT I (EASA) or CAT II (FAA).
- EGNOS V3 airborne receivers will be certified DAL-B, with integrity/continuity fault rates compatible with CAT I operations. Therefore the SBAS SA CAT I fault tree is similar to SBAS CAT I fault tree.
- SA CAT I was originally developed by FAA for operators authorized for ILS CAT II, which implies the use of DAL-A receivers. However, EASA requires a specific SA CAT I aircraft certification, with the use of certified system in AFM (Aircraft Flight Manual). Therefore the receiver fault rate requirements might be relaxed (ex. DAL-B).
- The SBAS SA CAT I fault tree based on SBAS CAT I fault tree needs to be validated, in particular:
  - the aircraft integrity/continuity risk of the combined use of DAL-B SBAS receivers and other airborne equipment like HUD or autoland needs to be compatible with the SA CAT I certification requirements.
  - the risk mitigation allocated to the pilot (specific training might be required).

Consequently, the use of EGNOS V3 receivers certified DAL-B is potentially compatible with the SA CAT I fault tree, but needs to be validated with the future SA CAT I aircraft certification requirements.

Additionally, the applicability of the fault tree developed for SBAS CAT I operations to SA CAT I operations would need to be validated and confirmed (in particular the fact that the pilot risk reduction of the SBAS CAT I fault tree is still applicable with a DH of 150 ft).
SBAS CAT II

The analysis of the functional level of safety for SBAS CAT II operations has been based on GBAS GAST D fault trees, knowing that GBAS GAST D targets CAT II and CAT III operations, so the results could be conservative for CAT II.

GBAS GAST D SARPs provide general integrity and continuity requirements equivalent to the SBAS ones. GAST D integrity and continuity requirements are those of GAST C ones plus additional ones to address specifically the faults generated in the ground subsystem. These additional GAST D requirements are more stringent than the general ones, and do not have equivalent requirements on the SBAS side.

GBAS GAST D fault trees for CAT III have been developed in SESAR. Four GAST D hazards identified for GBAS CAT III could be applied to SBAS CAT II. From these hazards, 3 could be supported by SBAS with DAL-B receivers and current integrity and continuity risks. The remaining hazard cannot be met with DAL-B receivers and current SBAS integrity requirements as defined for GBAS CAT III. Nevertheless the validity for CAT II of the assumption that the pilot cannot mitigate the integrity risk needs to be confirmed because ICAO Annex 10 Guidance Material on fault trees suggests that pilot risk reduction can be considered for CAT I (as it is done in SBAS CAT I fault tree) but not for CAT III, although it does not provide the respective information for CAT II. If the pilot cannot mitigate the hazard risk in CAT II operations, the use of other mitigation means would need to be considered (for example use of additional on-board equipment frequently available in commercial aircrafts, like autoland systems).

4.4.5 Costs and benefits

The costs and benefits have been estimated for ANSP and Airspace users for the two segments CAT I airports and CAT II/III airports, taking into account the size of associated airports (i.e. small, medium and large/very large).

The generic benefits for both SA CAT I and SBAS CAT II services are:

- For ANSPs, a reduction of the loss of revenues due to the capacity gained during adverse weather conditions;
- For Airspace Users, a reduction of delay and diversion costs.

At CAT I airports

For Airspace users

These operations will contribute to improve the access to the airport in low visibility conditions with a DH down to 150ft and therefore limit the flight delay and potential diversion or cancelation during low visibility.

For ANSP

These operations will contribute to improve the access to the airport in low visibility conditions and ensure revenue continuity.

The development of SBAS SA CAT I operations would be of interest at airports equipped with CAT I runways.

The required investment is limited and mainly dedicated to develop Instrument Approach Procedure (IAP) and Low Visibility Procedures (LVP) at the airport and training.
Assuming the SBAS SA CAT I service can be provided with the same SBAS CAT I with 10m VAL performance requirements, availability and continuity simulation results show coverage in the whole European area, and part of North Africa. Therefore all European airports could be initially targeted to implement SBAS SA CAT I operations.

The computed benefits (associated with revenue continuity) obtained with CAT II are the double than those obtained with SA CAT I (because of the assumption made on the ceiling distribution in low visibility conditions).

However, this has to be balanced with the development of SBAS CAT II operations which will require upgrading a CAT I runway into a CAT II runway and which is costly.

**At airports currently equipped with CAT II/III operations**

The development of SBAS SA CAT I or SBAS CAT II operations will be of interest as backup of existing CAT II/III procedures and will ensure revenue continuity.

Although the probability of requiring SBAS SA CAT I or CAT II operations to avoid closing runways in CAT II/III airports is very low (i.e. probability of ILS service unavailability during low visibility conditions), when it happens even for a few hours the cost can be high.

The implementation cost of these operations is expected to be low since the airports are already equipped with the required infrastructure and have already Low Visibility Procedures (LVP).

For airspace users, the cost associated with these potential new SBAS operations is the same and is related to equipping aircraft with DFMC SBAS receivers as well as training staff.

An overview of the estimated quantified costs and benefits is provided in Table 6.
<table>
<thead>
<tr>
<th>Services per segment</th>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| SABS SA CAT I at CAT I airport                           | 260 € per aircraft (IAP and LVP procedure development)                | 3,75h / years * :
                                                                 | 100€ per aircraft (DFMC/SBAS receiver)                                  | 2 € – 69 € (small to large airports)                                      |
|                                                          | 100€ per aircraft (DFMC/SBAS receiver)                                | 42,5h / year 25 € – 780 €                                               | 3,75h / years * :
|                                                          |                                                                      | 19€ – 2M€ (small to large airports)                                       |
|                                                          |                                                                      | 42,5h / years * :
|                                                          |                                                                      | 225€ – 23M€ (small to large airports)                                     |
| SBAS CAT II at CAT I airports                            | 1,96M€ (runway infrastructure and IAP and LVP procedure development) | 7,5h / years * :
                                                                 | 100€ per aircraft (DFMC/SBAS receiver)                                  | 4 € – 138 € (small to large airports)                                      |
|                                                          |                                                                      | 85h / year 43 € – 1,5 M€                                               | 7,5h / years * :
|                                                          |                                                                      | 19€ – 2M€ (small to large airports)                                       |
|                                                          |                                                                      | 85h / years * :
|                                                          |                                                                      | 450€ – 47M€ (small to large airports)                                     |
| SA CAT I or SBAS CAT II at CAT II/III airports           | 80€ per IAP procedure development                                     | 18€/hour of ILS unavailability                                          | 560€/hour of ILS unavailability                                           |
|                                                          | 100€ per aircraft (DFMC/SBAS receiver)                                |                                                                          |                                                                          |

*Table 6: Costs and Benefits associated with potential EGNOS approach services beyond CAT I*
5 CONCLUSIONS AND WAYFORWARD

5.1 Future potential EGNOS services

5.1.1 List of proposed new EGNOS based services

Consultation of European ATM community allows the identification of future applications that would benefit from EGNOS V3 services. These applications are:

- **Enhanced A-SMGCS application**: ADS-B is used to enhance the surveillance quality (by providing an additional surveillance means) at airports already equipped with A-SMGCS. This solution allows improving the A-SMGCS alerts and routing function (e.g. Follow the green function) or may also enable the implementation of additional alerts.

- **Alternative A-SMGCS applications**: ADS-B is used as a sole means to provide an alternative surveillance means with the required performances for an “A-SMGCS like”, i.e. an A-SMGCS with possibly a reduced number of alerts or functions.

- **SURF-IA (Enhanced Traffic Situational Awareness on The Airport Surface With Indications and Alerts)**: it consists in providing flight crew with visual awareness on the airport moving map display and indications and alerts (aural and on devices) about situations where collision hazard exists or a collision appears imminent.

- **SURF-A** consists in providing alerts to the pilot with respect to surrounding traffic during runway operations to prevent collision on the runway. SURF-A is similar to SURF-IA but does not include the use of a Cockpit Display of Traffic Information (CDTI) and the provision of indication.

- **EGNOS Vertical reference service**: EGNOS is used as a new altitude reference system; geodetic altitude is used instead of barometric pressure measurements to calculate the altitude.

- **Special Authorisation (SA) CAT I operations**: SA CAT I approaches are introduced as an operational credit to extend the instrument segment of a CAT I approach to allow CAT I operations down to a DH of 150 ft, subject to holding specific approval from the competent authority.

- **CAT II operations**: Equivalent to current CAT II operations.

In addition, assessment of constraints to implement a SBAS authentication service in the aviation context has been performed.
5.1.2 Consolidated SBAS requirements

These potential services that could be supported in the future by EGNOS require specific SBAS performances. The following table provides a consolidated view of the corresponding required values of the EGNOS technical parameters presented in Table 1, Table 3 and Table 5.

The following color code is used:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGNOS V3 performance specifications</td>
<td>Requirement met by EGNOS V3 specifications</td>
</tr>
<tr>
<td>Requirement exceeds EGNOS V3 specifications, but remains below EGNOS SDD commitments</td>
<td>Requirement that needs an improvement of EGNOS V3 specifications</td>
</tr>
<tr>
<td>Tbd: parameter to be defined, not available at present time</td>
<td>NA: Not Applicable</td>
</tr>
<tr>
<td>Requirement not defined in EGNOS V3 specifications</td>
<td></td>
</tr>
</tbody>
</table>
### Operations Indicators

<table>
<thead>
<tr>
<th>EGNOS V3 CAT I performance specifications</th>
<th>SA CAT I (Note 1)</th>
<th>CAT II (Note 3)</th>
<th>ADS-B to support enhanced A-SMGCS (Note 5)</th>
<th>ADS-B to support alternative A-SMGCS (Note 6)</th>
<th>SURF-A</th>
<th>SURF-IA</th>
<th>Vertical reference service (Note 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal accuracy 95%</strong></td>
<td>16 m (current commitment is 3 m)</td>
<td>15.4 m (Note 2)</td>
<td>6.9 m (Note 4)</td>
<td>&lt; 10 m (NACp=10) or &lt; 3 m (NACp = 11)</td>
<td>&lt; 10 m (NACp= 10)</td>
<td>&lt; 30 m (NACp = 9)</td>
<td>But &lt; 10 m recommended (NACp=10)</td>
</tr>
<tr>
<td><strong>Vertical accuracy 95%</strong></td>
<td>4 m (Note 2)</td>
<td>3.8 m (Note 2)</td>
<td>2 m (Note 4)</td>
<td>≤45 m (Note 7)</td>
<td>≤45 m (Note 7)</td>
<td>≤45 m</td>
<td>≤45 m</td>
</tr>
<tr>
<td><strong>Integrity risk</strong></td>
<td>2x10-7 / 150s</td>
<td>2x10-7 in any one landing</td>
<td>10e-9 in any one landing</td>
<td>≥ 10^{-7}</td>
<td>≥ 10^{-7}</td>
<td>10^{-5}</td>
<td>10^{-4} for indication and caution and 10^{-5} for warning</td>
</tr>
<tr>
<td><strong>Time to alert (TTA)</strong></td>
<td>6 s</td>
<td>6 s</td>
<td>2 s (recommended 1 s)</td>
<td>Tbd</td>
<td>≤10s</td>
<td>≤10s</td>
<td>≤10s</td>
</tr>
<tr>
<td><strong>Horizontal Alert Level (HAL)</strong></td>
<td>40 m</td>
<td>38.5 m</td>
<td>21 m</td>
<td>Tbd</td>
<td>Tbd</td>
<td>&lt; 0.1 NM (NIC=8)</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Vertical Alert Level (VAL)</strong></td>
<td>10 m</td>
<td>9.5 m</td>
<td>6.1 m</td>
<td>Tbd</td>
<td>Tbd</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Continuity risk</strong></td>
<td>8 × 10^{-6} /15 s 10^{-5} (up to NPA)</td>
<td>8 × 10^{-6} in any period of 15 s</td>
<td>4x10e-6 per 15 s</td>
<td>Tbd</td>
<td>10^{-5}</td>
<td>10^{-3}</td>
<td>10^{-3}</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>99%</td>
<td>99% to 99.999%</td>
<td>99% to 99.999%</td>
<td>Tbd</td>
<td>≥ 99.99%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Horizontal Velocity Accuracy (NACv)</strong></td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>&lt; 3m/s (NACv = 2)</td>
<td>&lt; 3m/s (NACv = 2)</td>
<td>&lt; 10m/s (NACv=1)NA</td>
<td>&lt; 10m/s (NACv=1)</td>
</tr>
</tbody>
</table>

**Table 7: Consolidated SBAS requirements**
| (Note 1) | Egis has obtained:  
|          | • the SA CAT I horizontal and vertical 95% accuracy requirements by linearization of ILS CAT I accuracy performance at a decision height of 150 ft, in a similar way as they were derived for SBAS CAT I at a decision height of 200 ft.  
|          | • the HAL and VAL (5σ value) by multiplying the corresponding accuracy requirement (2σ value) by 2.5, as described in RTCA DO-255A.  
|          | The integrity and continuity risk requirements correspond to the requirements for ILS stations of Level 2, targeted by EASA as the navigation mean to support ILS SA CAT I.  
|          | The TTA requirement corresponds to the one for ILS CAT I.  |

- Egis has obtained the SA CAT I accuracy requirements by linearization of ILS CAT I performance at a DH of 150 ft, and the HAL/VAL have been derived scaling the accuracy by 2.5. This is one of the methods used to derive SBAS CAT I requirements (with a DH of 200 ft instead of 150 ft).  
- The requirements obtained with this method are slightly more stringent than the performances targeted by EGNOS V3, although this difference is small (0.2 m for the vertical accuracy and 0.6 m for the horizontal accuracy). Nevertheless, the theoretical analysis of the final approach trajectory presented in D310, similar to the analysis done at ICAO to justify the VAL of 35 m for LPV-200, shows that the final segment trajectory with a VAL of 10 m does not penetrate the ILS CAT I OCS with a DH of 150 ft, which indicates that the VAL of 9.5 m could be relaxed to 10 m. In the case of LPV-200, the justification of the VAL of 35 m was also supported by flight tests.  
- The requirements obtained through other methods may be slightly different; for example, an aircraft manufacturer has identified HAL of 40 m and VAL of 10 m as acceptable values to potentially support SBAS CAT II autoland operations, and MASPS LAAS RTCA identifies a VAL of 10 m and a HAL of 17 m for GBAS CAT II/III operations.  |

- The presented CAT II requirements are based on equivalency of ILS CAT II requirements for information purposes only. It is recommended to derive SBAS CAT I requirements considering SBAS characteristics and its integration within the aircraft.  |

- Egis has derived:  
  - the CAT II accuracy requirements by linearization of ILS CAT II performance at a DH of 100 ft (see MASPS LAAS).  
  - the CAT II HAL and VAL requirements by scaling the 95% accuracy (2σ value) by 3.05 to get a 6.1σ value (which corresponds to the 10e-9 integrity risk).  |

- Requirements have been derived from ADS-B APT for the accuracy, Multilateration standard (ED117) for availability and continuity and ED87 for velocity accuracy which have been converted into ADS-B requirements and then SBAS requirements.  |

- Surveillance requirements have been derived from ED87 (version D and B) for accuracy and ED87 for velocity accuracy which have been converted into ADS-B requirements and then SBAS requirements. Experts expressed the need to increase vertical accuracy but it is not clear how it can be used. The value is derived from the ADS-B quantization.  |

- Experts expressed need for vertical accuracy improvement but real use is not yet clear. The value comes from the minimum value of Geometric Vertical Accuracy value defined in ADS-B MOPS.  |

- These requirements have been obtained from the stakeholders’ consultations in which stakeholder selected among a set of proposed values.
5.1.3 Feasibility study

Considering the expected performances of the EGNOS system as well as the enablers that would also be required to allow the deployment of the operations, the following conclusions can be raised about the feasibility of the services.

5.1.3.1 Enhanced and Alternative A-SMGCS

Theoretically EGNOS requirements to support ADS-B applications are in line with the existing performances of EGNOS V2 and the target EGNOS V3 performances (assuming the EGNOS V3 performances are at least equal to the EGNOS V2 performances) except for the continuity and availability.

However the following caveats have to be considered.

- There are no commitments from EGNOS V2 for ground operations. Current performances of the legacy system (e.g. 3m at 95%) are guaranteed “open air” with no obstacle and the legacy receivers are not certified for the ground operations. The error models of the receiver are defined for airborne operations. Similarly, the EGNOS V3 targeted performances are defined for airborne operations.

  Multipath models applicable for the ground will have to be defined by industrials and standardisation bodies and then an assessment of the suitability of SBAS performances for the services will have to be performed to guarantee EGNOS V2 or V3 performances could be sufficient.

- Although EGNOS V2 performance committed values inside the LPV-200 area are up to 3m of horizontal accuracy, such value may be difficult to ensure on the airport surface due to airport environment (e.g. interferences, reduced satellite visibility). EGNOS V2 may be sufficient for A-SMGCS operations which require NACp = 10 (HFOM<10m).

- On the other side, EGNOS V3 should be more capable to meet the demanding values (i.e. A-SMGCS operations requiring NACp = 11 or SURF-IA) with the required continuity and availability thanks to better residual errors and more satellites in sight.

  Nevertheless, the feasibility for EGNOS to provide horizontal accuracy < 3m should be confirmed.

- ADS-B surveillance applications have Horizontal Velocity Accuracy (NACv) requirements and there is no velocity accuracy requirements captured in EGNOS MRD (Mission Requirement Definition).

The availability of multipath model applicable to the ground could be a blocking point for the use of SBAS to support these applications, which are currently under development and for which the other required enablers do not present major issues.

5.1.3.2 Vertical reference service

The feasibility assessment focused on the user and system requirements, to understand the readiness level of the technologies required to deploy the new vertical reference service.
The required enablers are:

- Performance requirements;
- Aircraft equipment for the following Airspace Users:
  - Commercial Aviation (CA);
  - General Aviation (GA) and Rotorcraft;
  - RPAS.
- Ground segment;
- Standardization;
- Security issues; and
- Concept of Operations (CONOPS).

Due to the reduced maturity of the concept, it is hard to provide a definitive answer about feasibility of the service without a well-defined concept of operations and service architecture. As the service is further developed and standardised, the technical and operational feasibility will become clearer contributing heavily to the final decision.

The forward fit approach for CA and the long-term plan put in place for the equipage of the GA fleet would provide a solid ground for ensuring the Airspace Users buy-in. Due to the slow roll-out of the service, the disruptions would be minimal and the upgrades could be completed in time.

The Standardisation phase will deliver the required avionics and standards for altitude conversion and sharing of data between all stakeholders. Additionally, the Standardisation phase should provide the required confidence that the service can reach its required performance level.

The implementation of new vertical separation minima may be possible either globally once all the aircraft are suitably equipped or locally if it appears to be possible to implement them, even with a mixed aircraft equipage such as on final approach. This would bring benefits for both Airspace Users (AUs) as well as for ANSPs under the form of increased safety, reduced workload for both air crews and ATCOs as well as increased airspace capacity and improved fuel consumption.

Consequently it would be feasible to bring the new vertical reference service into operations within the timeframe identified by the study (2037-2057) provided that, once there is an agreement and decision between stakeholders for such change of paradigm and associated standards are available, the performance of EGNOS could be improved to support the required performance levels (presented in section 3.2.1 Table 3). Additionally, a clear way forward for the conversion between barometric and geodetic altitude needs to be defined and built into the vertical reference service CONOPS to ensure the feasibility of the service.

5.1.3.3 Beyond CAT I Operations

For SA CAT I, EGNOS V3 target performance requirements with VAL 10 m are likely to support SA CAT I operations, by equivalency with ILS CAT I performance.

Concerning CAT II, requirements derived by equivalence with ILS CAT II requirements are very stringent (integrity risk of 10e-9 in any one landing, TTA of 2 s (recommended 1 s), lower HAL and VAL requirements). These performances requirements resulting from direct linearization of ILS CAT II are likely to be too stringent for SBAS, specially the TTA and should be further investigated to consider
SBAS characteristics and its integration within the aircraft (in particular, preliminary results from a manufacturer are much less stringent).

In addition to the need of an operational EGNOS system with the commitments to meet the required performances, the main enablers required for SA CAT I and CAT II are the runway infrastructure required for each service, and the need of specific procedure design criteria and approval processes, which are already existing.

Consequently, there are no major stoppers found for SA CAT I operations (although the pilot risk mitigation needs to be validated) whereas for CAT II operations, improvements of EGNOS performances would be potentially required.

5.1.4 Safety analysis

The preliminary safety analysis that were conducted (both for the use of the same source of position for navigation and surveillance, and on beyond CAT I operations) indicated that the use of EGNOS for future service does have major impact on the EGNOS V3 system in general (i.e. ground system and receiver, which are already DAL B certified).

However, the validity and efficiency of mitigation means that have been identified for the use of EGNOS as the same source for surveillance and navigation should be confirmed.

Similarly, for the approach services beyond CAT I, the applicability of the fault tree developed for SBAS CAT I operations to SA CAT I operations would need to be validated by safety experts and confirmed and for CAT II, the possibility to consider the pilot as a mitigation means in CAT II operations should be confirmed and if not possible the use of other mitigation means would need to be considered (for example use of additional on-board equipment frequently available in commercial aircrafts).

Concerning the authentication service, the use of the authentication may increase the likelihood of loss of EGNOS service. SBAS authentication scheme shall be designed to limit this increase. The authentication function would need to be designed in a way it ensures high levels of availability and continuity (since it contributes to the loss of EGNOS service).

5.1.5 Service provision

From a service point of view, the new services (i.e. EGNOS-enabled ADS-B services and vertical reference service) could be categorised as a constituent service for Navigation.

Similarly, for authentication service, no specific advantage has been identified for using an operator different from the SBAS one.

The provision of the new services (i.e. EGNOS-enabled ADS-B services and vertical reference service) would oblige the ESP to complete a safety assessment for the functional change but it will not require them to set up new processes for safety oversight and safety performance monitoring.

The definition of specific Service Level(s) (SL) of the EGNOS Safety of Life service associated with the new services may be required but this would need to be confirmed.

5.1.6 Implementation timeline

The implementation of the new services will rely on the availability of the set of enablers.
The dates of associated possible deployment are summarised in the table below.

<table>
<thead>
<tr>
<th>Services</th>
<th>Date of possible initial implementation of operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced and Alternative A-SMGCS</td>
<td>2029</td>
</tr>
<tr>
<td>SURF-A</td>
<td>2021</td>
</tr>
<tr>
<td>SURF-IA</td>
<td>2025</td>
</tr>
<tr>
<td>Authentication service</td>
<td>Q1 2024</td>
</tr>
<tr>
<td>Vertical Reference system</td>
<td>2037</td>
</tr>
</tbody>
</table>

Figure 5: Implementation timeline

5.1.7 Cost and Benefits

The CBA investigated both the costs and benefits associated with the foreseen new services, for the main intended users: Airspace Users and ANSP, and the impact on the ESP.

The following table provides an overview of the costs and benefits per service and per main stakeholders (i.e. ANSP, Airspace Users and ESP).

For ADS-B operations and beyond CAT I operations, the benefits have been calculated per segment considering small, medium and large/very large airports and the average number of movements on these airports and a typical aircraft per type of airport for the airspace user perspective.

For the vertical reference service, the benefits have been quantified for the ECAC traffic and aircraft fleet only, in term of fuel savings for airspace users and increased capacity for ANSP, making distinction between oceanic and continental traffic.

Regarding the costs for the vertical reference service, the costs related to the redesign of the airspace, to implement the new routes at 700ft separation have not been taken into account.

The benefits shall be seen as conservative, since some of them could not be quantified, e.g. additional benefits based on the monetisation of reduction of delays for airspace users during low visibility, benefits taking into the real dates of low visibility when operations beyond CAT I could applied.

The following Table 8 provides a consolidated view of the costs and benefits presented in Table 2, Table 4 and Table 6.
<table>
<thead>
<tr>
<th>Services per segment</th>
<th>ANSP</th>
<th>AU</th>
<th>ESP</th>
<th>ANSP</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced A-SMGCS at airports already equipped with A-SMGCS</td>
<td>200K€ (update of A-SMGCS fusion process)</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Not quantified</td>
<td>Taxitime benefits: 70K€ to 2M€ (medium to very large airports)</td>
</tr>
<tr>
<td>Alternative A-SMGCS at airports not equipped with A-SMGCS</td>
<td>2.5M€ (Ground infrastructure, data fusion process, vehicles)</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Safety benefits*: 1K€ to 50K€ (small to medium airports)</td>
<td>Taxitime benefits: 14K€ to 250K€ (small to medium airports)</td>
</tr>
<tr>
<td>SURF-A/SURF-IA</td>
<td>NA</td>
<td>100K€ per aircraft + ADS-B IN equipment (DFMC/SBAS receiver)</td>
<td>Regulatory costs</td>
<td>Not quantified</td>
<td>Not quantified</td>
</tr>
<tr>
<td>Vertical Reference Service in Oceanic area</td>
<td>2037</td>
<td>NA</td>
<td>5.9M€</td>
<td>680K€</td>
<td></td>
</tr>
<tr>
<td>Vertical Reference Service in continental area</td>
<td>2037</td>
<td>500K€ per ANSP (ATM system upgrade for new data feed)</td>
<td>GA: 1.5K€ per aircraft (for retrofit)</td>
<td>No additional costs for forward fit for either of the AUs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2057</td>
<td>NA</td>
<td>3.8M€</td>
<td>23.3M€</td>
<td></td>
</tr>
<tr>
<td>SABS SA CAT I at CAT I airport</td>
<td>260 K€</td>
<td>100K€ per aircraft</td>
<td>NA</td>
<td>3.75h / years *: 2 K€ – 69 K€</td>
<td>3.75h / years *: 19K€ – 2M€</td>
</tr>
<tr>
<td>SBAS CAT II at CAT I airports</td>
<td>(IAP and LVP procedure development)</td>
<td>(DFMC/SBAS receiver)</td>
<td>(small to large airports) 42,5h / year 25 K€ – 780 K€</td>
<td>(small to large airports) 42,5h / years * 225K€ – 23M€</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------</td>
<td>----------------------</td>
<td>------------------------------------------------------</td>
<td>------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>SBAS CAT II at CAT I airports</td>
<td>1,96M€ (runway infrastructure and IAP and LVP procedure development)</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>NA</td>
<td>7,5h / years * : 4 K€ – 138 K€ (small to large airports) 85h / year 43 K€ – 1,5 M€I</td>
<td></td>
</tr>
<tr>
<td>SA CAT I or SBAS CAT II at CATII/III airports</td>
<td>80 K€ per IAP procedure development</td>
<td>100K€ per aircraft (DFMC/SBAS receiver)</td>
<td>NA</td>
<td>18 K€/hour of ILS unavailability</td>
<td></td>
</tr>
<tr>
<td>SA CAT I or SBAS CAT II at CATII/III airports</td>
<td></td>
<td></td>
<td></td>
<td>560 K€/hour of ILS unavailability</td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Quantified costs and benefits for the new EGNOS services

Note * Benefits have been computed per year considering the number of hours per year when the new SBAS service avoids a zero capacity runway.
Enhanced A-SMGCS operations:

- The implementation of the Enhanced A-SMGCS solution will be highly beneficial for Large and Very large airports as it is expected to increase the taxi time optimisation of 3% compared to their actual performance. This operational impact is estimated to save taxi time cost up to 573 000 euros for a large airport in a year. Compared to the initial investment of 200 000 euros for the Data fusion element it is highly profitable. For medium size airports the return on investment is lower and more than three years of operation would be required to reach the breakeven point.

Alternative A-SMGCS

- For the implementation of Alternative A-SMGCS for medium size airports, the taxi time improvement benefits are not sufficient to balance implementation costs and the return on investment will occur instantly if a major incident impacting 50% of their operations is avoided thanks to the solution implementation. Indeed, such event is expected to cost around 6 million euros in delay and cancelation costs for the airspace users. Alternative A-SMGCS solution on small airports of this segment will not be profitable unless it prevents two major incidents that each block 100% of the airport operation for a day. Nevertheless, the solution could allow small airport to gain a competitive advantage against other regional airport which would not be equipped, this additional commercial argument resonates especially for airline that would not have implemented SURF-A and SURF-IA services.

The breakeven point is mainly due to airspace users' benefit estimation and not from the ANSP perspective.

SURF-A/SURF-IA

- Added value of the situational awareness SURF A/ IA applications, would be relatively small and difficult to assess at airports which are already equipped with A-SMGCS (Enhanced or Alternative). In addition, the efficiency of these applications rely on the rate of equipped aircraft with ADS-B OUT which is mandatory for specific aircraft category by 2020 (but not for all aircraft). However, the majority of non-concerned aircraft with this regulation are mainly General Aviation aircraft and usually fly to small airports. This specific airport size would be the one which would the less beneficial from the A-SMGCS category, and thus where SURF-IA could be relevant.

Vertical reference service

- There are both qualitative and quantitative potential benefits that would support and enable the air traffic growth and would contribute to both safety of operations and improvement of cost-efficiency. Enough incentives are required to obtain the stakeholders buy-in.

SBAS SA CAT I operations

- The economic benefits of implementing SBAS SA CAT I are mainly derived to the reduction of the number of aircrafts diverted to other airports in low visibility conditions.

- For CAT I airports:
  - CAT I airports may need incentives for developing LVP, especially small airports for which the economic benefits may not compensate the required investment.
Most of the benefits would go to airspace users whereas most of the implementation costs are for the ANSP.

This could concern up to 70 small airports and 30 medium airports in 25 different European States.

- For CAT II/III airports
  - SA CAT I is used as a back-up of the ILS (with a DH higher than ILS CATII).
  - No additional infrastructure is required.
  - This could concern up to 46 small airports, 46 medium airports and 30 large/very large airports in 29 different European States.

**SBAS CAT II**

In CAT I airports, the economic benefits may not compensate the required investment, especially in small and medium size airports, which are the typical size of CAT I airports. In this case CAT I airports would probably prefer to invest in SA CAT I implementation (if the airport would absolutely need CAT II for their operations, they would probably have already invested in an ILS CAT II/III).

The implementation SBAS CAT II in CAT II/III airports would allow a backup in case of ILS service unavailability, as well as serving a mixed traffic with different capabilities (ILS, SBAS, etc.). Although the probability of ILS unavailability in low weather conditions is low, when it happens the savings thanks to SBAS services beyond CAT I can be significant, especially in large airports. Since the investment required to implement SBAS CAT II is limited to the cost of developing the Instrument Approach Procedure (IAP), it is very probable that CAT II/III airports would implement this type of procedures, provided there is sufficient traffic with the capacity of flying them.

### 5.2 Way forward

The study identifies the following recommendations as way forward.

**EGNOS-enabled ADS-B surveillance applications**

The following activities should be considered in the future:

SBAS requirements should be consolidated based on the final A-SMGCS surveillance requirements, which are under development. Moreover, the possibility for EGNOS to ensure HFOM < 3m and the availability of multipath models for surface operations using SBAS need to be assessed.

In terms of safety, the quantification of the safety barriers and the impact on the likelihood should be confirmed.

For the service provision, the need for a dedicated service level in the SDD for the provision of EGNOS-enabled ADS-B based services should be confirmed by airworthiness authorities and the EGNOS service provider.

The economic analysis has considered several assumptions to characterise the segmentation (e.g. the number of movements per year at the given airport, the aircraft type arriving at the airport, the formula for computing the arrival and departure fees) or to quantify the low level benefits and the costs (e.g. taxi time increase, system costs) based on the available information. These hypotheses have
allowed to provide benefit and cost values for each market segment. However, there are currently several activities that progress on each application definition and validation (e.g. SESAR) that will provide refined information by the end of SESAR Wave 1 (2020).

These generic costs and benefit results could be re-evaluated and refined. Lastly, representative airport could re-evaluate these generic cost and benefit results with the actual airport information and more precise information about the envisaged implementation (e.g. type of alerts) to obtain the actual costs and benefits.

The need for SBAS should be re-evaluated based on refined performance requirements and other available surveillance means in the future and the opportunity for SBAS should be reviewed by considering other applications and properly coordinated with European CNS long term strategy.

**Vertical reference service**

To progress on implementing this service, avionics industry will have to ask ICAO to develop a ConOps and put forward to a wider number of stakeholders to gage their interest. In the same time, discussions could be started with European and international organisations to understand the feasibility of such a change at both European and global level.

Furthermore, a demo mission which would include a mock-up service test with prototype should be first engaged, followed by the development of vertical reference box when sufficient confidence is obtained. As part of the mock-up service, a more mature CONOPS could be developed. Fast time simulations could also be run prior to the demo mission simulating the 700ft vertical separation minima and therefore providing an initial view on the concept of operations.

A more detailed study would also be required to understand the various requirements that are needed to support all phases of flights in all airspace types. The performance requirements identified as part of the project are meant to cover the most demanding operations, RPAS operations in VLL, however it is clear that not all operations will require such stringent requirements.

These activities would allow to validate the concept and the benefits that have been identified by the EASE team as part of this project and should help them build the business case for the service.

**Beyond CAT I operations**

The following activities are proposed to consolidate and continue the present study:

- Validate that SBAS DFMC receivers certified DAL-B have an associated integrity fault rate of 10⁻⁷ per approach.
- Validate the fault tree for SBAS SA CAT I operations
  - Validation of the assumptions, mainly of the pilot risk mitigation ratio, and the compatibility between the airborne integrity/continuity risk required by the future SA CAT I aircraft certification and the performance of the combined use of the SBAS DAL B receiver and the rest of airborne equipment (HUD, autoland, etc.).
- Derivation/consolidation of SBAS CAT II requirements and fault tree.
  - If the pilot cannot mitigate the risk, identify and evaluate other mitigation means (for example use of additional on-board equipment frequently available in commercial aircrafts).
- Consolidation of EGNOS performance requirements to support SA CAT I.
The requirements presented in this study are based on ILS CAT I Level 2 performances linearized at DH 150 ft. The theoretical analysis of the final approach trajectory presented in D310, similar to the analysis done at ICAO to justify the VAL of 35 m for LPV-200, shows that the final segment trajectory with a DH of 150 ft and a VAL of 10 m does not penetrate the ILS CAT I OCS. This indicates that a VAL of 10 m could be acceptable to support SBAS SA CAT I. In the case of LPV-200, this theoretical analysis was also supported by flight tests.

- Once EGNOS requirements to support SA CAT I and CAT II are consolidated, implement the corresponding enablers (ex.: develop procedure design criteria, update the corresponding standards, etc.)

The economic analysis has provided representative benefit and cost values for each market segment considering default values. For a minimum of 3,75 hours of use of SA CAT I per year, ANSP benefits are from 2K € for small airports up to 69K € for large airports; and Airspace Users benefits are from 20K € for small airports and 2M € for large airports. Benefits increase when the number of hours of use increases. The estimated maximum number of hours of use is 42,5 (in average).

Each airport should re-evaluate on a case by case these generic cost and benefit results with the actual airport information to obtain the actual costs and benefits they would obtain from the implementation of SBAS approach operations beyond CAT I.

**Authentication Service**

The study performed in the frame of the project provides a first analysis of the impact and operational constraints to be taken into account for the deployment of such service in the existing and future SBAS systems.

Further studies are required to fully design and specify the characteristics of such service. In particular, cryptographic studies need to be performed in order to determine the adequate values for the parameters identified in the study (key length, algorithms, refresh rate, etc.) taking into account the threats identified in this study.

In addition to the detailed design and definition of the authentication service, the architectural studies for the addition of the function to either existing or future systems needs to be performed.

Finally, a standardisation effort needs to be performed in order for the approach to be viable. This standardisation effort should be doubled by a regulatory framework development in order to ensure the possibility of using such a feature when it exists as well as potentially, the identification of areas and contexts for which a mandate for authentication service would be required.