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Evolution of SBAS/EGNOS Enabled Devices in Maritime

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ABSTRACT: The maritime sector was one of the first communities that recognized and exploited the opportunities and advantages provided by Global Navigation Satellite Systems (GNSS). In fact, GNSS have become the primary means of obtaining Position, Navigation and Timing (PNT) information at sea. Most of the ships in the world are equipped with GNSS receivers.
GPS provides the fastest and most accurate method for mariners to navigate, measure speed, and determine location. However, its performance can be enhanced by taking advantage of augmentation systems such as differential GNSS or Satellite-Based Augmentation Systems (SBAS/EGNOS), especially in terms of accuracy. Direct access to EGNOS in vessels can be achieved through EGNOS-enabled navigation receivers and EGNOS-enabled AIS transponders.
This paper provides an analysis of the number of onboard devices, mainly devoted to navigation purposes, and AIS transponders which are SBAS compatible. In addition, other equipment using GNSS positioning in the maritime and inland waterways domains are also considered for the analysis of SBAS compatibility, including inland AIS, Portable Pilot Units (PPUs) and Dynamic Positioning (DP) equipment. A first survey was done in 2017 to have an overview of the percentage of SBAS enabled devices available in the maritime market [8]. Since then, the analysis has been yearly updated to understand the market evolution in terms of SBAS compatibility and its main results are summarised in this paper.

1 INTRODUCTION

The maritime sector was one of the first communities that recognized and exploited the opportunities and advantages provided by Global Navigation Satellite Systems (GNSS). In fact, the introduction of GNSS represented a great revolution in the maritime domain.

It is acknowledged that GNSS have become the primary means of obtaining Position, Navigation and Timing (PNT) information at sea. Most of the ships in the world, even in the recreational and leisure field, are equipped with GNSS receivers. At the beginning, GNSS was only used as a means to know the current position; at present, GNSS receivers are connected and integrated with other equipment such as Integrated Bridge Systems, ECDIS, ARPA, GMDSS, AIS, LRIT or VDR. In this sense, GNSS has become the positioning source to implement additional functionalities.

Accuracy is one of the main requirements when talking about maritime positioning. Nowadays maritime users can take advantage of augmentation systems such as differential GNSS or SBAS/EGNOS, as they provide an adequate answer, especially in

terms of accuracy. The first step is to have a receiver compatible with these services.

Therefore, the objective of this paper is to present an assessment done covering the last four years to estimate how many GNSS shipborne devices available in the market are SBAS ready.

1.1 *What is EGNOS?*

Satellite navigation systems provide positioning and timing services over wide geographical areas (typically continental or global coverage) with high accuracy performance. However, a number of events may lead to positioning errors. Satellite-Based Augmentation Systems (SBAS) are designed to augment the global navigation constellations by broadcasting additional signals from geostationary (GEO) satellites. EGNOS (European Geostationary Navigation Overlay Service) is the European SBAS providing an augmentation service to the Global Positioning System (GPS) and to Galileo in a future.

EGNOS has been designed to broadcast a GPS-like ranging signal in Europe with embedded corrections, providing improved performances over GPS. With EGNOS, all compatible navigation receivers can benefit from enhanced accuracy, availability and continuity over GPS.

The EGNOS coverage area is Western Europe, but could be readily extended to include other regions within the broadcast area of the geostationary satellites, such as Africa or Eastern Europe.

In addition to EGNOS, there are other SBAS around the world with similar characteristics and compatible among them. Figure 1 presents the coverage of the different SBAS systems in the world.

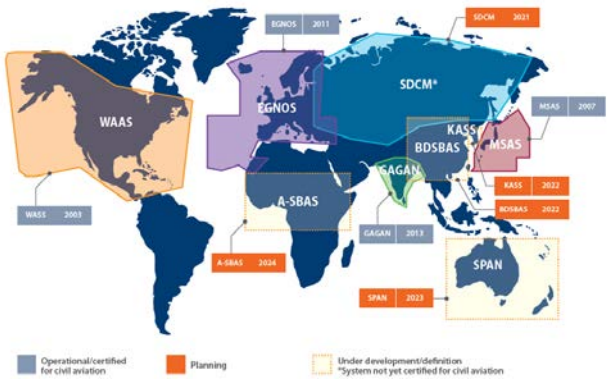

Figure 1. SBAS indicative service areas [4]

The main objective of the EGNOS Open Service (EGNOS OS) is to improve the achievable positioning accuracy by correcting several error sources affecting the GPS signals. The corrections freely transmitted by EGNOS geostationary satellites contribute to mitigate the ranging error sources related to satellite clocks, satellite position and ionospheric effects. The EGNOS OS minimum accuracy is specified in the table 1 [2].

Focusing on the maritime domain, EGNOS is able to provide, over its coverage area, the same type of information offered by a DGNSS service (i.e. differential corrections and system integrity information). This information can be used to improve the accuracy in the position and to protect users against potential system failures.

Table 1. EGNOS OS Horizontal and Vertical Accuracy

Accuracy	Definition	Value
Horizontal	Corresponds to a 95% confidence bound of the 2-dimensional position error in the horizontal local plane for the Worst User Location	3m
Vertical	Corresponds to a 95% confidence bound of the 1-dimensional unsigned position error in the local vertical axis for the Worst User Location	4m

EGNOS accuracy performance, as shown in Table 1, is in line with DGNSS one (<5m (95%) - IALA Guideline 1112 [13]). Therefore, SBAS can be considered as a means to complement DGNSS services.

2 ONBOARD GNSS RECEIVERS - SOLAS CONVENTION

The SOLAS Convention [11] is the reference to be consulted to understand what kind of navigation equipment can be found onboard vessels. The SOLAS Convention is considered as the most important of all international treaties concerning the safety of merchant ships. Chapter V within SOLAS Convention deals with safety of navigation; it identifies navigation safety services which should be provided by Contracting Governments and sets forth operational provisions applicable in general to all ships on all voyages. Of special interest is Regulation 19 within chapter V, which establishes the carriage requirements for shipborne navigational systems and equipment.

2.1 *Satellite Navigation Equipment*

According to that Regulation [6], all ships irrespective of size are required to be fitted with a GNSS receiver. This could be a GNSS receiver which might or might not be equipped to receive differential corrections, since the carriage of a DGNSS receiver or an SBAS enabled receiver is not mandatory. The question is: Does a simple GPS receiver fulfil the IMO requirements in all navigation phases?

The most common system used as primary means of navigation is GNSS, however currently available GNSS do not fulfil IMO requirements in regards to accuracy and integrity in all the navigation phases.

IMO Resolution A.915(22) [6] recognises that differential corrections can enhance accuracy (in limited geographic areas) to 10 m or less (95%) and also offer external integrity monitoring. In this sense, this Resolution mentions the following techniques that can improve the accuracy and/or integrity of GPS and GLONASS by augmentation:

- Differential correction signals from stations using the appropriate maritime radionavigation frequency band between 283.5 and 325 kHz for local augmentation.
- Craft or receiver autonomous integrity monitoring.

- Integrated receivers combining signals from GPS, GLONASS, LORAN-C and/or Chayka (a Russian terrestrial radionavigation system, similar to LORAN-C).
- Wide area augmentation systems using differential correction signals from geostationary satellites such as EGNOS for Europe, WAAS for the United States and MSAS for Japan.

A more recent IMO Resolution, A.1046(27) [7] on the "Worldwide Radionavigation System" refers to Chapter V of the SOLAS Convention, Regulation 13, when talking about navigation in harbour entrances, harbour approaches and coastal waters. At the same time, IMO Res. A.1046 [7] establishes that: where a radionavigation system is used to assist in the navigation of ships in such waters, the system should provide positional information with an error not greater than 10 m with a probability of 95%. It is important to note that this is a requirement to be accomplished by the radionavigation system.

The broadcast of differential corrections, understood as aids to navigation to be provided by maritime authorities, is not mandatory. It is up to the Contracting Governments to decide to provide this service based on the volume of traffic and the degree of risk. Hence, when navigating in waters without a maritime DGNSS service, it is of special interest the access to SBAS corrections or even as a backup when this DGNSS service is provided. According to the GSA report on user needs [12], EGNOS can provide solutions in areas where IALA beacons are not deployed or coverage is sparse and there is high traffic density.

2.2 *AIS onboard devices*

Automatic Identification System (AIS) is an autonomous and continuous broadcast system, operating in the VHF maritime mobile band. The objective of AIS is to exchange navigation data such as vessel identification, position, course, speed, etc. between participating vessels and shore stations.

Section 4.1.1 of the IALA Guideline 1082 [5] is devoted to shipborne AIS, that is, Class A and Class B devices. According to that Guideline and the AIS Technical Standards (ITU-R M.1371), Class A equipment complies with the IMO AIS performance standards. Whilst the Class B are compatible with Class A, they are not fully compliant with IMO requirements and report less frequently than Class A.

AIS uses an absolute referencing system to determine position. This position is normally derived from a GNSS receiver. AIS Class A devices can obtain position information from an internal GNSS receiver or from the vessel's primary GNSS receiver. However, Class B equipment only uses the AIS internal GNSS sensor to obtain the position information.

According to the SOLAS Convention, AIS carriage (Class A) is mandatory for ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size. In addition, EU Directive 2002/59/EC [3] states that fishing vessels with a length of more than 15 metres overall shall be fitted with an AIS (Class A) which meets the performance standards drawn up by the IMO.

AIS devices are also used in inland waterways. being compatible with IMO's maritime AIS standards and considering specific requirements for inland navigation which are gathered in the Inland AIS standard [15].

3 ADDITIONAL USES OF GNSS RECEIVERS

GNSS receivers are also included in several types of systems to support marine operations. Portable Pilot Units and Dynamic Positioning systems are two esamples.

3.1 *Portable Pilot Units*

Pilots usually get on a vessel to support the captain in order to carry out the necessary manoeuvres to introduce that vessel in a port. To assist pilots in this process there are technological aids, which use GNSS, called Portable Pilot Units (PPUs).

PPUs can be defined as tools to be carried onboard vessels by the pilots in order to support the decision making process when navigating in confined waters or visibility is compromised, for instance, at night or under bad weather conditions.

IMPA Guidelines [16] on the design and use of PPUs recommend DGNSS enabled positioning devices (GBAS or SBAS based) as the minimum to provide enhanced accuracy in the positioning.

3.2 *Dynamic Positioning systems*

Dynamic Positioning is the result of applying a combination of techniques to automatically maintain the position of a vessel to a desire point, with regard to a fixed reference or to a moving object.

Several sensors are involved in this process, including positioning sensors, motion sensors and wind sensors. All of them provide information to be used by the DP algorithms in order to calculate the vessel's position and the magnitude and direction of the forces to be applied to maintain the position.

DP systems' applications (e.g. drilling, dredging, survey,…) are increasing in the maritime industry. Different types of ships are now being fitted with DP systems to improve control and handling over vessels at sea.

4 METHODOLOGY

Three phases have been followed to carry out the survey:

1. Definition and scope
   The scope of the analysis is focused on the satellite navigation equipment and AIS devices approved to be used in SOLAS and non-SOLAS vessels. In

addition, inland AIS equipment, Portable Pilot Units (PPUs) and Dynamic Positioning (DP) and marine surveying equipment were also considered. As a starting point, it was decided to gather the list of receivers and their datasheets and user manuals.

2. Survey

The navigation receiver equipment and AIS devices list taken as reference was extracted from the database published by the Spanish Merchant Marine, as can be found in the Spanish Ministry of Transport website [10] and also from the MED Database [9]. These inventories catalogue SOLAS and non-SOLAS authorised devices including brand, model and dates of homologation and expiration for each equipment. Besides, the list of approved Inland AIS equipment in accordance with the Rhine Vessel Inspection Regulations [14] was taken as reference.

A first survey was done in 2017 to have an overview of the percentage of SBAS enabled devices available in the maritime market. This assessment was published in 2018 in the TransNav Journal [8]. Since then, the analysis has been yearly updated to understand the market evolution in terms of SBAS compatibility.

3. Analysis

The analysis of the characteristics sheets, brochures, owner's manuals, webpages or technical specifications of the listed receivers and AIS devices has led to know if the device is SBAS compatible and, among the SBAS compatible ones, if EGNOS is explicitly mentioned.

5 SURVEY RESULTS

5.1 *Satellite Navigation Equipment Survey*

5.1.1 *SOLAS*

The number of satellite navigation devices authorised for its use in SOLAS vessels increased in the last year to reach a total of 32 available devices in the market from 8 different manufacturers. The evolution in the last four years can be seen in Figure 2.

To be highlighted that 30 out of 32 devices are SBAS/EGNOS compatible, although EGNOS is explicitly mentioned in the datasheets or user manuals of 26 products.

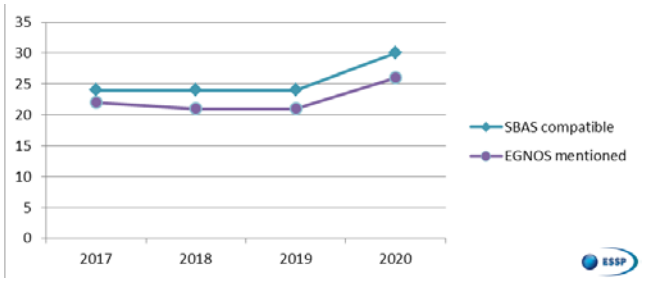

Figure 2. SBAS compatible device evolution in SOLAS satellite navigation equipment

It is important to note that 100% of the authorised manufacturers to provide SOLAS GNSS-based equipment have at least one SBAS-enabled receiver within their products portfolio. The SBAS capability is included in 94% of the satellite navigation devices approved for SOLAS vessels. EGNOS is explicitly mentioned in the 81% of the datasheets or user manuals of these equipment.

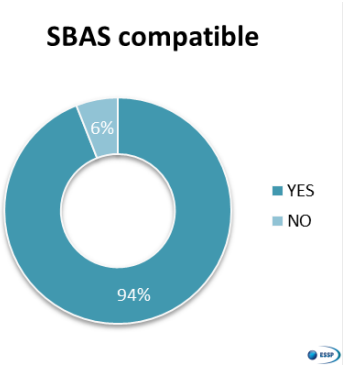

Figure 3. Percentage of SBAS compatible devices within SOLAS navigation equipment

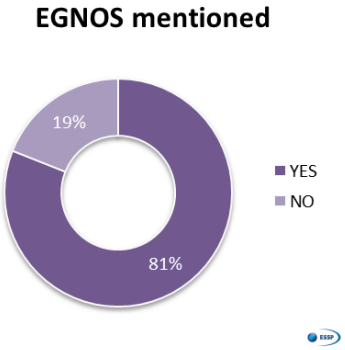

Figure 4. Percentage of SOLAS navigation equipment which mention EGNOS

5.1.2 *Non-SOLAS*

A total of 537 satellite navigation devices used in non-SOLAS vessels, from 26 different brands, were checked in this assessment. Leaving apart discontinued products, the number of satellite navigation devices available in the market for non-SOLAS vessels increased in the last year to reach a total of 346 available devices in the market. The evolution in the SBAS capability depicted in Figure 5 shows a steadily growth over the past four years.

To be highlighted that 309 out of 346 devices are SBAS/EGNOS compatible, although EGNOS is explicitly mentioned in the datasheets or user manuals of 259 products.

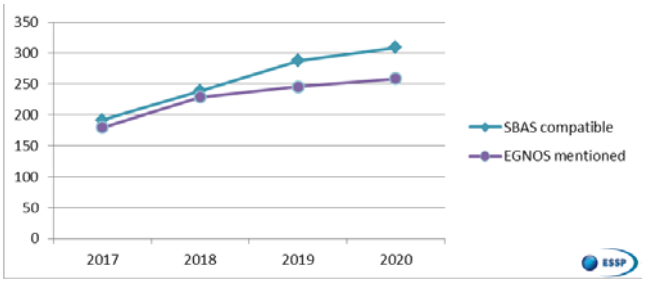

Figure 5. SBAS compatible device evolution in non-SOLAS satellite navigation equipment

It is important to note that 96% of the non-SOLAS navigation equipment manufacturers have at least one SBAS-enabled receiver within their products. The

SBAS capability is included in 89% of the non-SOLAS satellite navigation devices. EGNOS is explicitly mentioned in 75% of the datasheets or user manuals of these equipment.

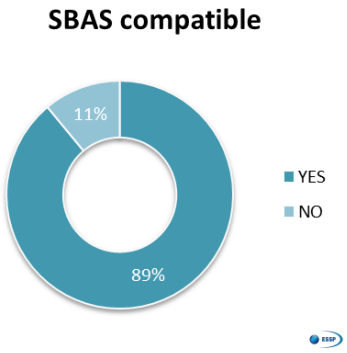

Figure 6. Percentage of SBAS compatible devices within non-SOLAS navigation equipment

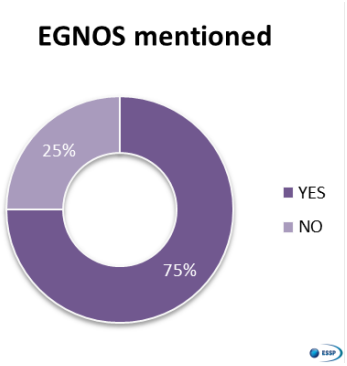

Figure 7. Percentage of non-SOLAS navigation equipment which mention EGNOS

5.2 *AIS Equipment Survey*

5.2.1 *SOLAS*

There are 17 AIS devices authorised for being used onboard SOLAS vessels, from 14 different brands. The number of SBAS capable devices increased in 2019 with a slight decrease in 2020. This decrease should be further analysed in the coming years since it corresponds solely to one device. The number of SOLAS authorised AIS devices is very limited to yield statistical conclusions without an extended period of analysis.

The evolution in the last four years can be seen in Figure 8. To be highlighted that 12 out of 17 devices are SBAS/EGNOS compatible, however, EGNOS is only mentioned in the datasheets or user manuals of 7 products.

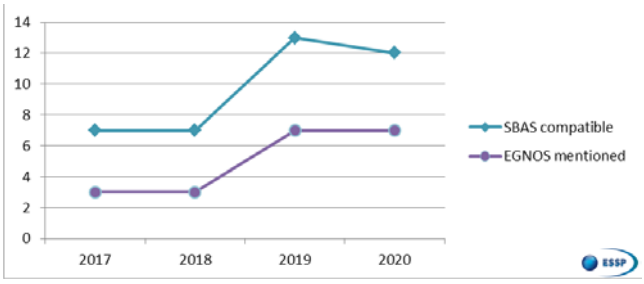

Figure 8. SBAS compatible device evolution in AIS SOLAS equipment

Almost a 65% of the authorised manufacturers to supply AIS SOLAS equipment have at least one SBAS-enabled receiver within their products portfolio. The SBAS capability is included in 71% of the onboard AIS SOLAS devices. EGNOS is explicitly mentioned in the 41% of the datasheets or user manuals of these equipment.

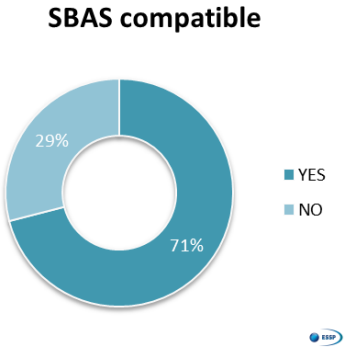

Figure 9: Percentage of SBAS compatible devices within AIS SOLAS equipment

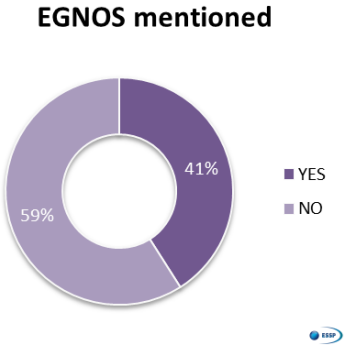

Figure 10. Percentage of AIS SOLAS equipment which mention EGNOS

5.2.2 *Non-SOLAS*

The datasheets of 70 AIS devices for non-SOLAS vessels were analysed, from 26 different brands. Excluding discontinued products, it was observed that the number of shipborne AIS devices available in the market for non-SOLAS vessels increased in the last year to reach a total of 64 available devices in the market. The evolution in the SBAS capability depicted in Figure 11 shows a steadily growth over the past four years.

In this case, only 20 out of 64 devices are SBAS/EGNOS compatible and EGNOS is explicitly mentioned in the datasheets or user manuals of 11 products.

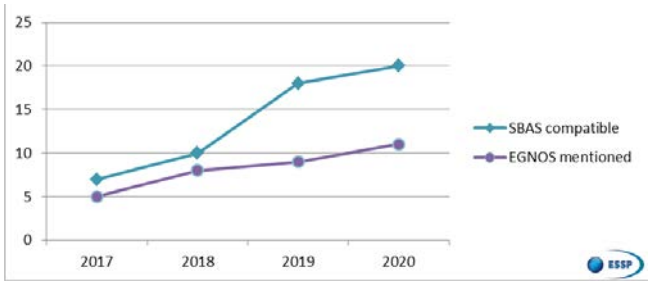

Figure 11. SBAS compatible device evolution in AIS non-SOLAS equipment

Even though the number of AIS non-SOLAS devices which are SBAS compatible increases every year, the percentage is still low. The SBAS capability is included in 31% of the AIS non-SOLAS devices. EGNOS is explicitly mentioned in the 17% of the datasheets or user manuals of these equipment.

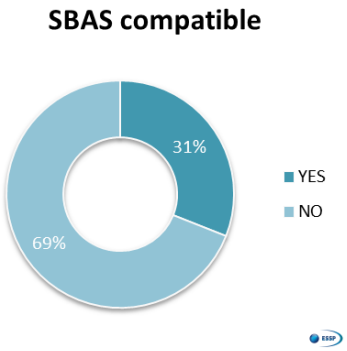

Figure 12: Percentage of SBAS compatible devices within AIS non-SOLAS equipment

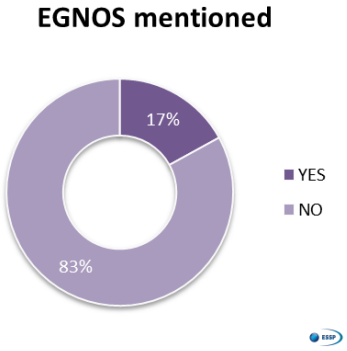

Figure 13: Percentage of AIS non-SOLAS equipment which mention EGNOS

5.2.3 *Inland AIS*

The datasheets of 30 inland AIS devices, from 19 different brands were analysed. Excluding discontinued products, there are 10 out of 27 devices which are SBAS/EGNOS compatible and 7 of them explicitly mention EGNOS in the datasheets or user manuals.

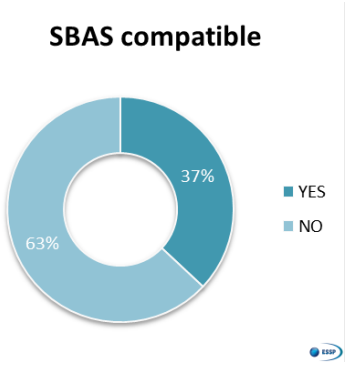

Figure 14: Percentage of SBAS compatible devices within inland AIS equipment

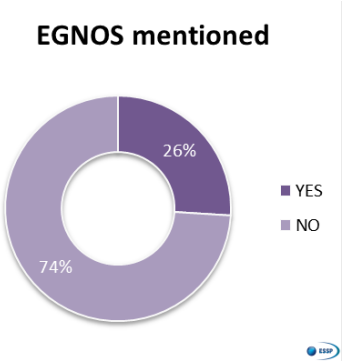

Figure 15: Percentage of inland AIS equipment which mention EGNOS

5.3 *Portable Pilot Units Survey*

The assessment of PPUs is based on 19 products available in the market in 2020. Most of them, 18, are SBAS/EGNOS compatible and EGNOS is mentioned in 15 products. In percentage, this compatibility can be seen in the following figures.

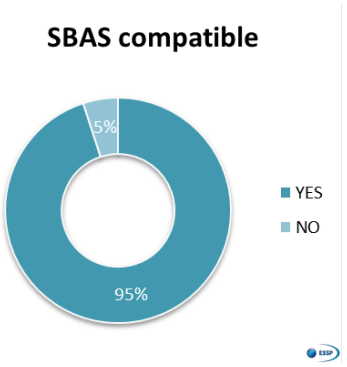

Figure 16: Percentage of SBAS compatible PPUs

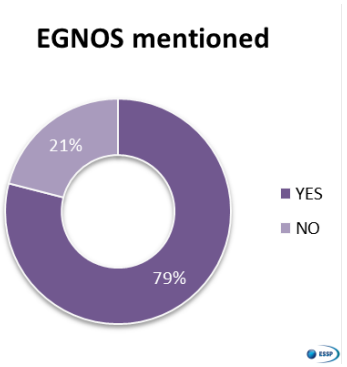

Figure 17: Percentage of PPUs which mention EGNOS

5.4 *Dynamic Positioning Survey*

This section covers other maritime positioning equipment, not included in the previous categories, which is used in maritime applications, such as, dynamic positioning or marine surveying.

A total of 29 devices were analysed, being a 100% of them SBAS/EGNOS capable. EGNOS is explicitly mentioned in 20 of them.

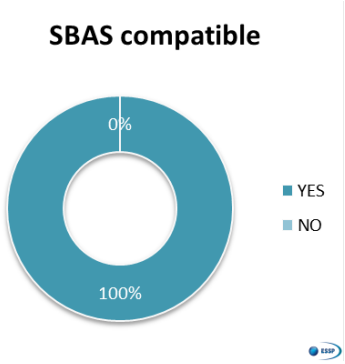

Figure 18: Percentage of SBAS compatible devices within DP systems

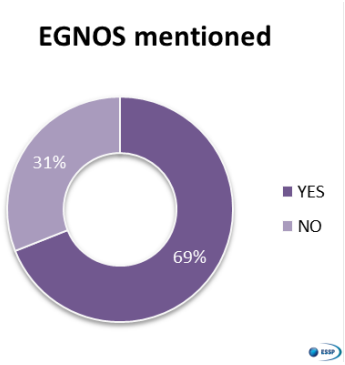

Figure 19: Percentage of DP equipment which mention EGNOS

6 CONCLUSIONS

Many GNSS receivers currently available on the market are able to receive and process EGNOS messages and can be used to support numerous applications. As a result of using EGNOS, a better position performance can be obtained.

According to the EGNOS OS SDD [2], the EGNOS OS horizontal minimum accuracy, corresponding to a 95% confidence bound of the 2-dimensional position error in the horizontal local plane for the Worst User Location, is 3 meters. Nevertheless, the observed errors are usually lower than this upper bound [1]. Therefore, the accuracy requirement established in IMO Res. 1046 [7] about navigation in harbour entrances, harbour approaches and coastal waters with an error not greater than 10 m with a probability of 95% is fulfilled by far when the GNSS receiver is EGNOS enabled. It is also important to remark that IMO Resolution A.915(22) [6] considers SBAS/EGNOS as one of the techniques that can improve the accuracy of GPS.

To take advantage of this improved accuracy, direct access to EGNOS in vessels can be achieved through:

- EGNOS-enabled navigation receivers:
  94% of the GNSS-based equipment authorised to be used in SOLAS vessels are SBAS/EGNOS compatible. Concerning the GNSS-based equipment used in non-SOLAS vessels, the 89% of devices are SBAS/EGNOS compatible.
- EGNOS-enabled AIS transponders:
  71% of the AIS devices authorised to be used in SOLAS vessels are SBAS/EGNOS compatible. This percentage is lower in the AIS non-SOLAS devices, around 31%.

In addition to navigation receivers and AIS transponders, there are other types of devices which take benefit of SBAS/EGNOS for their operation. This is the case of PPUs and DP systems.

EGNOS is usually activated in PPUs to obtain a better accuracy in specific operations such as the entrance and navigation through locks or in docking and turning manoeuvres. This is especially useful when visibility is reduced and big vessels require access to ports with difficult entrance.

EGNOS is also used in DP systems, mainly as a free of charge back-up system to other paid augmentation services.

Choosing SBAS/EGNOS-enabled receivers leads to an accurate position information. The advent of new standardised receivers, following common implementation guidelines will lead to an improvement in safety in navigation and an enhancement of those services based on position information.

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