IALA WORKSHOP ON THE FUTURE OF MARINE RADIOBEACON DGPS/DGNSS

WORKSHOP REPORT

27 to 31 January 2020

Northern Lighthouse Board Headquarters

Thomas Southall
Workshop Secretary

31 January 2020

10, rue des Gaudines – 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01 – Fax +33 (0)1 34 51 82 05 – contact@iala-aism.org

www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

This page intentionally blank

Report of the workshop on the Future of Marine Radiobeacon DGPS/DGNSS

Executive Summary

The workshop on the Future of Marine Radiobeacon DGPS/DGNSS was held between the 27 and 31 January 2020 at the Northern Light House Board Headquarters, Edinburgh, Scotland.

The workshop was very well attended by 49 participants from 22 countries.

The workshop participants considered the various presentations that were made and through discussion it was noted that:

- IALA recognises the important need to inform the mariner, in a clear and timely manner, if GNSS becomes unreliable;
- National competent authorities should take decisions based upon the volume of traffic and degree of risk and the need to ensure that integrity information is provided;
- contemporary GNSS stand-alone services do not provide integrity information to the users;
- satellite based augmentation services (SBAS) provides system integrity information, but use the same frequency band as GNSS and are therefore equally susceptible to jamming and spoofing;
- current implementations of Receiver Autonomous Integrity Monitoring (RAIM) are considered inadequate due to the current lack of maritime specific RAIM algorithms;
- while the IALA maritime radiobeacon DGNSS concept improves positional accuracy somewhat, its main utility today is the provision of real-time integrity information;
- the IALA DGNSS concept is globally harmonised and compatible with most shipborne GNSS receivers but there is uncertain levels of use;
- the IALA DGNSS frequency allocation is recognised as a significant asset in global harmonisation;
- many DGNSS service providers are facing difficulties in continuing their services with ageing equipment requiring significant investments;
- some service providers have decided to discontinue their DGNSS services, while others have upgraded their equipment, but the majority have not made up their mind yet and are seeking guidance; and
- several different architectures are available and can modernise DGNSS implementation in a more cost effective way.

Consequently, the workshop agreed that IALA should consider:

- encouraging IALA members to ensure that GNSS integrity information is provided in their area of responsibility;
- encouraging IALA members who discontinue their DGNSS services, to seek alternative ways of informing mariners, in a clear and timely manner, if GNSS becomes unreliable; and
- identifying alternative new and innovative ways of providing GNSS integrity information to mariners and find ways to speed up their development, including:
    - harmonised maritime GNSS user integrity algorithms;
    - encourage the development of MSR test specification and its introduction on all vessels; and
    - the introduction of R-Mode and other solutions for mitigating GNSS vulnerabilities.
- how best to co-ordinate this work with other international bodies to achieve globally harmonised solutions.

Taking into consideration some of these key findings, a draft guideline was produced which can be found in Annex D. Participants produced the framework and key points to cover in each section. The draft Guideline will be forwarded to the PAP, ARM and ENG committees for further development.

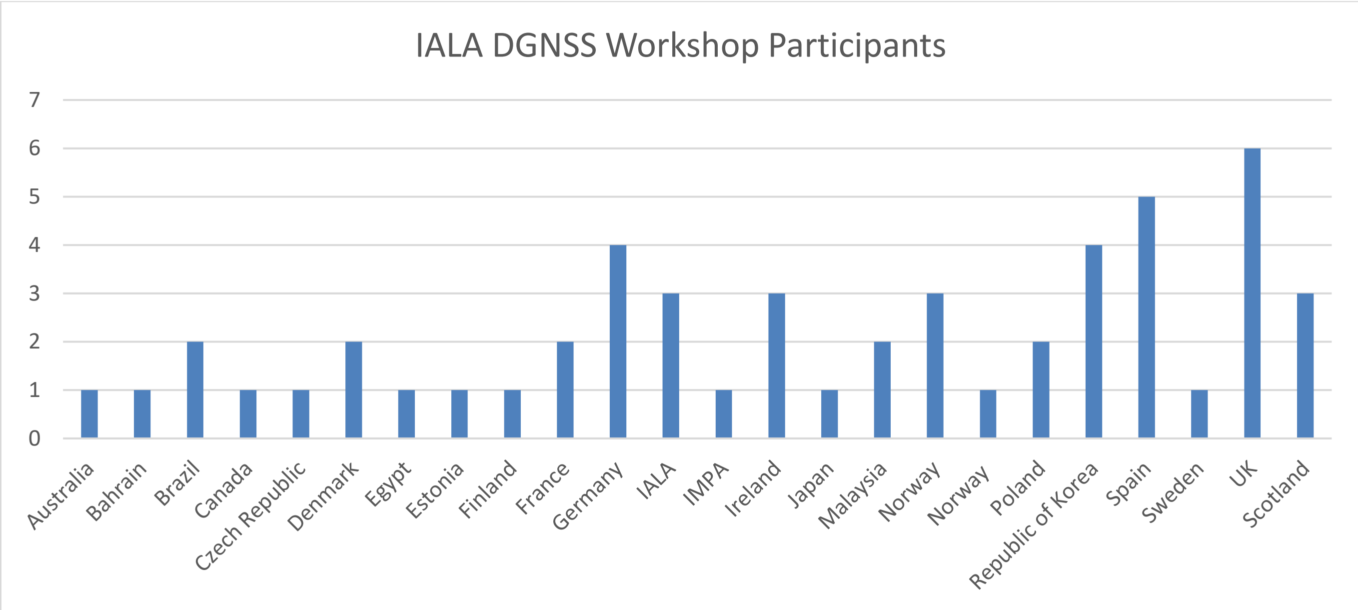
Contents

Report of the IALA Workshop on the Future of Marine Radiobeacon DGPS/DGNSS

1. INTRODUCTION

The workshop on the Future of Marine Radiobeacon DGPS/DGNSS was held between the 27 and 31 January 2020 at the Northern Light House Board Headquarters, Edinburgh, Scotland.

49 participants from 22 countries participated in the Workshop plus three members of the IALA secretariat. An analysis of the attendance is shown in graph format below:



Workshop participants were provided with the details of the file sharing system which will be available for the exchange of documents, presentations and photographs.

2. OPENING OF THE WORKSHOP

2.1 Welcome from Mike Bullock - Chief Executive, Northern Lighthouse Board

Mike Bullock, Chief Executive, Northern Lighthouse Board (NLB) welcomed participants on behalf of the Northern Lighthouse Board to Edinburgh. He gave an overview of the NLB's organisation, history and what roles the NLB fulfil. The NLB is one of the three General Lighthouse Authorities of the United Kingdom and was established in 1786.

The NLB is responsible for ensuring correct and reliable AtoN provision around Scotland and the Isle of Man including the response to wrecks or new dangers. The Non-Executive Board is made up of many senior law officers and sheriffs in Scotland as well as technical experts and the Patron of the NLB is HRH The Princess Royal.

Mike Bullock provided further detail of the NLB's assets including two vessels, Pole Star and Pharos. The Northern Lighthouse Board is proud to employ its own apprentices. The Board also has a base in Oban which has facilities for the maintenance and storage of buoys.

Having been founded in 1786 the NLB is famous for employing the legendary engineering family, the Stevensons, for around 150 years. Its most iconic lighthouse is the Bell Rock built in 1811.

He concluded by stating it was a privilege to have everybody here in Edinburgh and hoped for a productive week.

2.2 Welcome from IALA Omar Frits Eriksson - Deputy Secretary-General

Omar Frits Eriksson, IALA Deputy Secretary-General, welcomed participants on behalf of IALA. Omar began by providing an overview of IALA. The two strategic goals of IALA are to develop and harmonise AtoN and to ensure that they are used by all coastal states. He then explained the responsibilities of the four technical committees and the seven standards that the committees produce and their link to the Recommendations and Guidelines.

Omar then examined the lifecycle and hype cycle of DGNSS and where the technology currently sits in its lifespan. The obligations of each contracting government under SOLAS were examined with particular reference to chapter V regulation 13.

IALA's transition from an NGO to an IGO and the organisation's cooperation with other maritime organisations was explained to participants. The Diplomatic Conference will take place in Malaysia February 2020. He concluded by inviting participants to make the workshop fruitful.

2.3 Working programme of the week and expectations, Phil Day - Chair of the IALA ARM Committee

Phil Day, Chair of the ARM Committee and Northern Lighthouse Board Director of Operations, introduced the programme for the week (Annex C) and gave a safety and administrative briefing which can be found on the workshop fileshare.

The expectation for the week is to produce a draft guideline on the future of DGPS/DGNSS, network and understand what is happening with DGPS and what options are available when deciding what to do with the service and infrastructure.

The following statements were read out to participants with no response received:

> *If anyone present have the knowledge of any patents, including pending Patents, held either by themselves or by other organisations or individuals, the use of which may be required to practice or implement the content of IALA Documents being developed or worked on in this workshop then please advise the secretary.*
>
> *IALA has a policy regarding compliance with the General Data Protection Regulations. IALA will include a list of participants with their contact information in the report of this workshop. Any participant who wishes to remove their information from the participants list should advise the secretary as soon as possible.*

2.4 History of marine radiobeacon DGPS/DGNSS, Dr. Alan Grant - GRAD

Dr. Alan Grant gave a presentation on the history of the marine radiobeacon DGPS service. This included the need for augmentation and how DGPS works. Each available GNSS was examined including how they are used. Dr. Grant then introduced the typical equipment used for DGNSS such as a reference station and an integrity monitor. He went on to describe the initial operations of DGNSS and its growth around the world in the 1990's and 2000's.

The role of IALA of coordinating the system and maintaining the table of DGNSS stations around the world was also examined. In summary, DGNSS is an evolution and we are at a point where we can discuss where we can go next.

2.5 Maritime requirements and standardisation position, Peter Douglas – Navigation Manager NLB

Peter Douglas updated participants on a range of matters relating to maritime requirements and standardisation position. In particular, he covered requirements related to which equipment could be used for safe navigation on the ship, maritime positioning and integrity amongst other standards that relate to DGPS and integrity.

3. SOURCES OF POSITION INTEGRITY

3.1 Marine radiobeacon DGPS/DGNSS, Michael Hoppe - WSV

Michael Hoppe provided an overview of the different options for marine radiobeacon DGNSS. This included the different architectures (classical, network, SBAS) and the different options for integrity monitoring (pre and post). He went on to provide a summary regarding RTCM SC104 developments on a generic broadcast standard to allow for all GNSS signals to be corrected.

The presentation concluded with a short overview regarding user receivers, included in all the IMO receiver performance specification, and even ones being developed today for multi-frequency constellations.

3.2 Receiver Autonomous Integrity Monitoring, Chris Hargreaves - GRAD

Chris Hargreaves informed participants about receiver autonomous integrity monitoring (RAIM) covering how it works and what it does. He also examined the current capabilities, or lack thereof and potential expansion that may benefit the future of maritime navigation.

3.3 Satellite Based Augmentation Systems, Manuel Lopez - European GNSS Agency

Satellite-based augmentation systems (SBAS) are becoming a cost-efficient solution to complement DGNSS infrastructure. As described in IALA Guideline 1129, SBAS can be used by maritime authorities as a source of differential corrections to be re-transmitted by IALA beacons and/or AIS/VDES infrastructure. The SBAS signal-in-space can be used directly by the vessel, however as described in IALA Guidelines 1152, maritime authorities need to take into account several considerations. The European Commission, the European GNSS Agency, the European Space Agency and the EGNOS Service Provider are working together to offer a specific service for maritime: EGNOS L1 Maritime Service.

3.4 Commercial services, Angus Scott – Wartsila

Angus Scott explained that there are a very small number of suppliers in the commercial GNSS precise positioning market. These suppliers offer the prevailing technology of PPP (Precise Point Positioning) providing sub-10cm positioning with very high degrees of redundancy, reliability and support. Key markets include DP, survey & construction, pipe/cable-lay, dredging and renewables. Commercial rates are extremely high for both hardware and correction signals. Most suppliers receive user requests to integrate IALA DGNSS receivers into their hardware so they can utilise IALA DGNSS as a fall-back solution.

3.5 Question and answer session

A number of questions were asked from the floor and discussion highlighted the following:

- There was general consensus that the maritime RAIM implementations are currently not adequate and should be harmonised. It was believed that the IMO should consider requesting a test specification from the IEC.
- There was a discussion regarding the differences between maritime and aeronautical RAIM which concluded that the RAIM algorithms are generally similar, but the operational environment is already defined for aviation, but there is significant work required to understand the maritime operational environment (noise, multipath etc) which would need to be considered in the definition of a suitable algorithm.
- It was further noted that the evolution of maritime user requirements could lead to changes in the algorithm used. Currently, algorithms are designed to identify single failed satellites, however with the move to multi-constellation receivers, a new algorithm may be needed to ensure efficient use of all available satellites and frequencies. Advanced RAIM and maritime M-RAIM were mentioned as future developments.
- A general discussion on the maritime use of SBAS covered how the technical use of SBAS in a type approved receiver, once available, should be usable within any SBAS service area. The political issues of recognising a maritime user and how maritime safety information (MSI) is promulgated were also discussed and the potential benefit of IMO recognition of a maritime SBAS, noting that this was discussed previously and the IMO decided there was no requirement to recognise augmentation. It was noted that there is ongoing discussion between different SBAS providers regarding maritime user recognition. **Finally, there may be benefit in IALA providing an input to the IMO and other bodies seeking clarification and reconsideration of SBAS recognition, whether as part of the IMO WWRNS or other means.**
- A question on the planned evolution for EGNOS maritime service V3 – A.915 was asked to the effect that if IMO Resolution A.915 was updated prior to 2025 (the planned evolution date) would this affect the EGNOS service level? Without knowing what changes were made to the maritime requirements, it was not possible to answer this question completely, only that the service provided would be tailored appropriately.

4. VIEWS AND OPINIONS

4.1 View of the mariner, David Patraiko - The Nautical Institute

David Patraiko presented the view of the mariner and provided feedback received from various sections of the seagoing community. Reliability, accuracy and access to a free service are all key to mariners, however, there is little knowledge of differential GPS. The Nautical Institute promote loss of GNSS drills. The feedback received also stated that:

- +/- 10 metre accuracy is acceptable;
- Most docking is done by eye;
- Radar overlay gives an integrity check;
- Differential accuracy is good for:
  - Port approach
  - Narrow channels
  - Rate of turn
  - Speed
  - Precision for large ships is a growing need
  - Maybe needed for autonomous shipping

With a view to the future mariners felt the way forward was a need for reliability and accuracy, consideration to Cyber Security (Jamming/Spoofing) and not detecting faults. In addition, there is a desire for reliable resiliency, inertial systems and R-Mode.

4.2 View of the DGPS infrastructure provider, Tamas Horvath - Alberding

Alberding GmbH is a German GNSS software and hardware development company with 25 years of experience in high accuracy satellite positioning. The company actively participated in the development of innovative solutions for maritime and inland waterway DGNSS service providers, including the DGNSS VRS approach and pre-broadcast integrity monitoring using off-the-shelf GNSS receivers. Alberding software and hardware solutions are used by AtoN service providers around the world. The company plays a significant role in the development and introduction of R-Mode, a terrestrial backup to GNSS, and is also involved in research projects for providing integrity checked RTK and PPP corrections via AIS/VDES in combination with waterway information.

Alberding GmbH is committed to support radiobeacon system operators willing to modernise their existing DGNSS infrastructures. Emerging solutions (e.g. EGNOS Maritime Safety Service and M-RAIM) will certainly offer an alternative approach to provide the necessary integrity information to maritime positioning. However, those systems are still a long way from being practically usable.

In our opinion the short/mid-term maintenance and modernisation of radiobeacon DGNSS stations are necessary to guarantee that users are not left without a reliable source of radionavigation, until the new systems become fully operational. Moreover, the value of the existing infrastructure and the ITU-allocated frequency band, especially in the light of new types of services, such as R-Mode should not be underestimated.

4.3 View of the DGPS infrastructure provider, Cato Eliassen – Kongsberg

During the last decade Kongsberg Seatex has refitted or built new IALA beacon stations around the globe. 10 years ago, Kongsberg was awarded the contract in UK for the retrofit of GLA DGPS system. In this project a new generation of IALA reference and integrity stations was delivered. A new DGNSS Central Monitor was developed in close dialogue with the technicians in GLA.

Since 2010 the equipment has been delivered to several countries. Being a manufacturer of both DGNSS reference stations and VDES base stations Kongsberg Seatex supports the development of R-Mode and is a partner in the R-Mode Baltic project. Kongsberg Seatex also manufactures type approved multi system GNSS receivers and participates in both IALA and IEC to support standardisation.

4.4 View of the receiver manufacturer, Tobias Ehlers – BSH

Tobias Ehlers presented the point of view of a test laboratory for maritime approval and at the same time the administrative obligation to serving safety of life at sea and environmental protection. He laid out BSH's requirements for current and future DGNSS.

Tobias concluded by stating that BSH strongly recommends continuing DGNSS services, he recommended the future use of Multi-GNSS-Augmentation and continued research for an alternative terrestrial ranging/ positioning system to reduce vulnerability and weaknesses of GNSS like jamming & spoofing

4.5 Question and answer session

A number of questions were asked from the floor and discussion highlighted the following:

- It was recognised that IEC test standards for the MSR were in need of development and identified that an organisation/person is needed to take the lead in this task.
- In regard to R-Mode and positioning that provides sufficient geometry is essential.
- If you have a calculated R-Mode range and compare that measurement with the calculated GNSS position that you have then you have an uncorrelated test method (assuming independent time is used in R-Mode).
- Integrity monitoring will be a vital function going forward regardless of which option authorities decide to adopt with regards to DGPS / DGNSS. The output from this workshop should reflect this.

- IALA should examine integrity and how we coordinate this work between organisations. Consideration should be given as to what can IALA do to help get test standards in place.
- Today's technology is great, but it can fail. Reliability of position is correct onboard – worst case
- The range of R-Mode is up to 200km but less than that at night.
- Over reliance on technology – high end user ok – how do we move from first class innovation to something of use to the bridge team that assists the mariner.
- Participants noted that the onboard environment is very complex - everything is a system and mariners have to understand all of these algorithms. Positioning is just one system that mariners have to be aware of and so there should be a simple solution regarding resilient PNT.
- Interference from solar cycles every 11 years effect GPS/GNSS and so therefore we must use a multi frequency approach or augmentation such as SBAS to ensure the integrity of the system.
- MSR Performance standard was completed in 2015 and it is on the IEC work plan but we need to have someone who has the time and financial support to get the work underway.

5. CASE STUDIES

5.1 View of authority opting to maintain current service (GPS L1), Jeffery van Gils and Dr. Alan Grant

Jeffrey van Gills provided a presentation to the workshop for Dr. Alan Grant to deliver regarding the Netherlands position on the matter. The presentation covered facts and figures about the EEZ of the Netherlands, their responsibilities, choices regarding DGPS/DGNSS and way forward.

Taking into account the previous few years the Dutch administration were challenged as there was a lack of sufficient maintenance and as a result the systems were not in an ideal way and were outdated.

In order to renew the system several actions were then taken. The management were made aware of the need and users were asked if they knew they were using the signals provided. Only a few mariners knew if they were using it. This result raised the question that should we educate mariners and authorities regarding DGPS/DGNSS?

It was considered whether the Netherlands should deliver the same service or something more to support future innovation. After long discussions, examining their responsibilities and the status of the infrastructure at that time they chose to continue the current service and support future innovation such as R-Mode.

Another action taken was to connect to the NETPOS system, a Governmental surveying system with centre meter accuracy.

Having gone through this process participants were urged to keep the DGPS beacon system until they have a new one and it is tested. There is a Dutch saying "Gooi je oude schoenen niet weg voor dat je nieuwe hebt" (Don't throw away your old shoes before you have new ones).

In conclusion there is an option to stop the service and save a lot of money, but what happens if the current GNSS service is not working or give false information? What if you didn't detect it with an automatic system or other means. Are you responsible for alerting the mariner?

5.2 View of authority opting to renew the service, Shwu-Jing Chang and Dr. Alan Grant

On behalf of Shwu-Jing Chang, Dr Alan Grant gave a presentation regarding DGPS provision in Taiwan China and the decision to renew the infrastructure. The presentation covered the background, geography recent developments and needs that lead to the decision to renew.

The drivers for renewing the DGPS service in Taiwan China were the limited due to the amount of shipping space and the need to get accurate information to the mariner when it is required.

5.3 View of authority opting to provide multi-constellation augmentation, Michael Hoppe - WSV

Michael's presentation explained the opportunity for a maritime authority on how it provides correction information to more than one constellation, along with why it does so and what it envisions as the future of the service. The presentation went on to inform participants about what made this option attractive, what hardware is used, how integrity is managed and the implications to mariners and their receivers.

Finally, the presentation explained the approach used in Germany where corrections to GPS and GLONASS are provided.

5.4 View of authority opting to re-broadcasting 3rd party corrections, Juan-Francisco Rebello - Puertos del Estado

The DGNSS-GBAS service (for example using local EGNOS / EDAS data) is a public service available to the mariner in an open and free-way (although the AtoN service implies the payment of duties in certain cases). These services have been established under Chapter V Regulation 13 of the SOLAS Convention, depending on the volume of traffic and degree of risk, and operated according to IMO resolutions and IALA technical documents. These documents must be maintained, at least until DGNSS-SBAS systems are operational with integrity and its receivers are onboard for users.

A decision-making model and SWOT analysis for the future of DGNSS in Spain was presented to participants, an excerpt is shown below:

S	W	O	T
STRENGTHS	**WEAKNESSES**	**OPPORTUNITIES**	**THREATS**
20 YEARS OF CONTINUOUS DGPS SERVICE	Structure of the Spanish National AtoN service (decentralized management/ 28 Port Authorities)	IALA SUPPORTS THE USE OF SBAS IN MARITIME AND THE TRANMISSION BY AIS#17.	DGPS decommissioning in some countries.
BUDGET APPROVED	Difficult to get involved in EU funding opportunities due to lack of human resources in the National AtoN Service.	e-Nav development: Need for PNT systems, and Autonomous ships.	Users don´t clearly demand DGPS service continuity. Sometimes they are not even aware that their receivers are using DGPS.
SOME OLD DGPS EQUIPMENT CAN BE RE-USED	No multimodal approach (no Spanish National Radionavegation Plan yet).	Integrity requirements for PNT.	Multimodal approach (not only for marine user (pay for it)
EGNOS SERVICE PROVIDER (Service Level Agreement: quality and liability.		IMO requirements for port navigation and AtoN positioning (1 meter).	GNSS and SBAS could make GBAS radiobeacon stations redundant.

However, the most important matter is the service itself and the means of signal transmission could be adapted to different systems, although the range of the IALA-Radiobeacon systems may be useful in certain environments.

It is necessary to bear in mind that if the systems are abandoned the infrastructure will not be available in the future for other new systems that could possibly use them.

As a result of the decision-making process the following actions were agreed upon in Spain:

Maintain the DGNSS service as an AtoN Service under SOLAS Convention, provided by the National Competent Authority, until will be available free of charge to the user some systems based on signal from satellites or other terrestrial systems.

However, the State (Spain) can decide to decommission any transmission systems (AIS, R-Mode, ...), taking into account the traffic and risk in all the Spanish coastal or maintain it in some areas, with some level of service and by some system of transmission.

The management of the DGNSS/DGPS service should be done by Puertos del Estado.

Re-engineering of the current DGPS Network, based in the EGNOS/EDAS Service with centralised scheme in the areas with TSS far away as Finisterre and Strait of Gibraltar and busy traffic areas as the space between Balearic islands-Valencia-Barcelona, and the Guadalquivir river, without local backup system, using the equipment available if possible.

5.5 View of authority opting to discontinue services, NOGUCHI Hideki – Japanese Coastguard

Hideki's presentation described the history of DGNSS service in Japan and the process of discontinuation of the service, especially, what issues were considered in such process. The presentation also mentioned of the future possibility of terrestrial PNT service in Japan.

Japan discontinued DGNSS provision 1 March 2019 and has not received any negative feedback from mariners navigating in Japanese waters. Issues that were taken into consideration in 2018 to decide on the future of DGNSS were:

- The accuracy of GPS met the IMO standard;
- Number of onboard GPS receivers sold with only DGPS capability is only a few thousand, less than one twelfth of number of all onboard GPS receiver sold in the last ten years;
- QZSS provides 1 metre accuracy;
- GPS week number rollover on 7 April 2019; and
- New radio regulation on spurious emission in 2022

5.6 View of authority opting to discontinue services, Martin Bransby – GRAD

Martin presented the view of the US Coast Guard which is in the process of closing its DGPS provision across the United States. Following a review and public consultation (where little feedback was received) the decision was made taking into account the following factors:

- There are no carriage requirements;
- Widespread use of the Wide Area Augmentation System (WAAS);
- Continued GPS modernisation;
- Additional civil frequencies allow for correction of Ionospheric error;
- Reduced availability of consumer grade DGPS receivers;
- Federal Railroad Administration has no NDGPS requirement for Positive Train Control; and
- Agriculture sector uses commercial DGPS services.

On 3 Jul 2017, The U.S. Coast Guard Deputy Commandant for Operation (DCO) signed a decision memo directing the phased decommissioning of DGPS between 2018-2020 and the United States will discontinue Differential GPS augmentation by 2021. The current Nationwide DGPS system consists of less than 20 maritime DGPS broadcast sites

This timeline will allow the few remaining users to gain experience with and switch to replacement systems (e.g., WAAS, RTK.) The decision to terminate broadcast of the GPS correction signal underwent extensive evaluation and it was ultimately decided that this service was unsustainable.

Martin then introduced the decision to discontinue services in Australia. The rationale for taking this decision can be found by following the link here - https://www.amsa.gov.au/safety-navigation/navigation-systems/australias-differential-global-positioning-system.

5.7 View of authority currently undecided on the future of its services, Bjornar Kleppe

Bjornar's presentation indicated some results from a field measurement campaign of radio navigation signals along parts of the Norwegian coast during 2018. Some of the results can be seen in the table below:

Availability	Avaialbility if GPS-position was available			CEP95% (95% of positions inside radius of PPP position)			Number of GPS positions with error >10m	Number of GPS positions having error > 10m corrected to error < 10m		Continuity (15 min w/o alarm) provided no alarm (10 sek) at start		
GPS	EGNOS	DGPS	EGNOS and/or DGPS	GPS	EGNOS	DGPS	GPS	EGNOS	DGPS	EGNOS	DGPS	EGNOS and/or DGPS
99,89 %	99,22 %	62,71 %	99,69 %	1,30m	0,91m	0,96m	1,5	1,13	1,0	97,24 %	95,93 %	99,73 %

From the field measurements the Norwegian Coastal Administration (NCA) were able to identify, for the area measured, that DGPS coverage was less than expected, adjacent beacons do not fully provide redundant coverage and EGNOS coverage is excellent. The improvement in accuracy when using DGPS and EGNOS is minor and that the local environment really effects performance.

It also estimated some of the key navigation receiver capabilities believed to exist on ships sailing in Norwegian waters and also identify some aspects of DGPS believed to be relevant when considering the future of that system.

Going forward the NCA will take into account arguments for and against renewal. The arguments for are:

- Equipment is installed on many ships;
- DGPS fixed alarm threshold;
- Coherence of services between countries; and
- Possible future upgrade to R-Mode.

The arguments against are:

- DGPS is not SOLAS-mandated on ships or as an AtoN;
- User difficulty in assessing proper receiver operation; and
- Vulnerable to false beacons, GPS-spoofing at beacon.

5.8 The General Lighthouse Authorities of the United Kingdom's position on DGPS, Commodore Rob Dorey – Trinity House

Commodore Rob Dorey described the elements of the UK's DGPS/DGNSS infrastructure. He noted that the approach to decide what to do with the infrastructure is dependent upon many factors particularly the shape of each countries coastline but the focus must be upon the mitigation of risk.

After careful consideration the GLA have decided to cease transmissions on DGNSS in March 2022 and not re-invest in the infrastructure. This is decision has been taken for many reasons, particularly it was recognised that in addition to RAIM and SBAS developments we also have a backup for PNT utilising traditional methods of navigation that rely on a well-trained mariner must not be forgotten.

Currently the GLA are undertaking an internal discussion within Government to identify if any other stakeholders not related to the maritime sector wish to take the service on. The infrastructure may be retained in order to accommodate future technologies.

5.9 Question and answer session

The question and answer session included focus upon the content of the proposed draft Recommendation and Guidelines that will be output from this workshop. Discussion highlighted that:

- It's recognised that GNSS alone meets the expectations of mariners regarding accuracy and therefore integrity is the main driver for augmentation.
- If a coastal state is aware of errors, then they must get this information to the mariner quickly as an MSI or Maritime Service.

- Training of the mariner is important, however, it is of concern that ships crews are reducing in numbers. Additionally, sea time for mariner training is reducing and this has an impact upon experience and knowledge.
- The mariner still requires technology to support them but unless IMO carriage requirements are updated then most ships will not adopt the equipment. There is a reasonable expectation that as ships become more autonomous, more reliable positioning equipment with greater redundancy will be required. However, autonomy shouldn't be confused with unmanned vessels of the mariner.
- A nation deciding on the future of their DGNSS / DGPS infrastructure is recommended to go through a consultation process. The question to stakeholders must be worded carefully so that it is open and does not contain leading questions (ref. IALA Guidelines on User Consultations). There could be an annex that includes an example questionnaire to be used for the user consultation process.
- The source of integrity, such as RAIM and SBAS, should be standardised. There is a need to consider how best to take this forward to the IMO. In the Guideline a timeline of relevant systems and activities should be included.
- It is important to provide notification of any changes in service to the stakeholders. Considering standards take approximately 5-10 years, bodies are encouraged to give enough time to take this time into account.
- What level of notification should we provide to our users.
- There will be a phased change towards new technology unless mandatory carriage and a date given when to change. Flag states could be making recommendations to their registry to renew technology onboard.
- It was noted that a ship lasts for 30 years and bridges are re-equipped every 10 years.
- IMO Resolution A.915 doesn't currently recognise emerging technologies and there is a compelling need for it to be updated;
- The risk lies with lower tonnage and non-SOLAS vessel. We can't lose focus on the ships that are less well equipped.
- It was noted that IMO sets out 'minimum' requirements and performance. National administrations can set higher standards if they choose.
- In the Guideline we should state the pros and cons of each option. What questions should bodies consider when making the decision to renew DGNSS/DGPS infrastructure.
- It should be recognised there is not one solution that fits all.
- Solutions including what could be done pro-actively with the infrastructure.
- We should keep in mind continuity of shore-based systems between each country as vessels will not change from one system to another.
- It is very difficult to get global buy-in to one system. It would be regrettable to lose a system that is universally compatible.
- The implication of stopping DGPS transmission on AIS base stations that receive corrections from IALA beacons, should be considered.
- Is there a survey or study of jamming/spoofing incidents? There is a US Coast Guard website for recording jamming or spoofing.
- The Guideline should help users by describing what the consequences could be of each scenario such as keeping infrastructure for R-Mode or switching off radiobeacons.
- Another consideration would be to keep DGPS transmissions but in a lower availability. Could we tolerate a degrading service as we decommission?

- Consideration as to the implications and consequences to neighbouring states when you have a combined service.
- There is a need to capture the follow-on work. We need a standard for maritime RAIM and a standard for SBAS.
- Consideration should be given as to how we get the Multi System Receiver type approved and onboard ships?
- Authentication – when receiving corrections how do you know they are coming from a valid source and not as a result of 'spoofing'.
- Cyber security is a consideration we need to make especially when decommissioning sites as they maybe more susceptible.
- Should this be framed as an e-Navigation service as we are moving information from A-B and IALA has Guidelines on how to describe the services. This may make the concepts easier to handle in a modular form.
- We should not forget that we have allocated frequencies for data exchange for maritime use. These frequencies could be used for more services such as warnings on jamming. We have a very valuable asset and we must not lose it.
- Maritime services on PNT and S-100 product specifications must be handled on this matter in the future.
- Whatever IALA does it must be recognised that we may need to accommodate different languages. This may have connotations on matters such as coding.
- Yesterday we were advancing to accommodate new technologies but today there is a lot of talk about decommissioning. The technology is advancing but we are withdrawing when we should improve safety.
- It should be noted that Recommendations should contain high level guiding principles which are technology agnostic whereas guidelines will go into far more detail and describe technical solutions.
- Recommendation: The integrity is a must to transmit to mariners.
- Vulnerabilities of some of the solutions is also an issue. These should be highlighted to the user by the swift publication of MSI.
- User level integrity that RAIM provides and system level integrity are two different types of warnings that the Guideline should consider. You may not get the red light if it is a system wide alarm and we should understand what determines these warnings.
- Number of challenges with RAIM – harmonisation and work at the IMO.
- SBAS problems – coverage is predominately in the northern hemisphere and there are large parts of the world that currently have no integrity system. The guideline will be global so should try to address taking SBAS forward to areas such as the southern hemisphere that currently have not engaged with the technology.
- The mariner is currently unlikely to see an integrity alert on bridge equipment. How will the integrity alarm be integrated in the bridge systems to alert the mariner this maybe a question to take forward to IMO.
- WAAS trials in Canada have been proven to be successful and includes an integrity alarm. There is no legislation preventing the use of WAAS in the maritime sector in Canada.
- RTCM has conducted a study of SBAS receivers and it was found that a high percentage did not use the integrity component of the SBAS message. There needs to be standardisation to ensure safe use.
- SBAS transmissions from the satellite share the same vulnerabilities as GNSS.
- It was stated that EGNOS EDAS is more resilient when it comes to jamming or spoofing because it is transmitted over the internet.

- It would be positive if current DGPS systems remain in force whilst other technologies come to fruition.
- Operational commitments on accuracy should be specified.

6. FUTURE HARDWARE OPTIONS

6.1 High level discussion on potential considerations and options (hardware, frequency assignment benefits), Dr. Stefan Gewies - DLR

Dr. Stefan Gewies gave an overview of the current disposition of the marine radio beacon service. This included an analysis of coverage and AIS ship traffic patterns. It was found that marine radio beacons (in operation at the beginning of 2019) served majority of ships with GNSS code correction service and a significant number of vessels received more than one, two or three signals. When deciding what to do regarding DGPS/DGNSS authorities should consider:

- Continue legacy DGNSS service
  - Keep transmission of GNSS corrections and integrity information ongoing
  - Add additional signal components
  - Add additional channel(s)
- Discontinue legacy service
  - Use existing channels for new applications
  - Use entire marine radio beacon band for new applications

Stefan then explained the findings and structure of the R-Mode project in the Baltic Sea. R-Mode is a potential back-up for GNSS. He concluded that marine radio beacons have a high potential to provide a service to the mariner. R-Mode can be added as an additional service on marine radio beacons. MF R-Mode can fulfill the user requirements if the ambiguity issue is solved and the sky-wave can be mitigated. Using a wider R-Mode signal would help to solve ambiguities and mitigate sky-wave impact. The final conference of the project R-Mode Baltic will take place in September 2020.

6.2 Korean positioning system and R-Mode, Dr. Sang Hyun Park - KRISO

Dr. Park explained the current status of the marine PNT service in the Republic of Korea and introduced the future of marine PNT policy with the radiobeacon DGNSS service. In particular, the Republic of Korea is pursuing MF beacon R-Mode R&D to utilise the current radionbeacon DGNSS infrastructure for establishing a resilient PNT environment. Also, future PNT policy has been established so that the radiobeacon DGNSS infrastructure can be utilised for various marine PNT services.

6.3 Potential e-navigation services, Dr. Thomas Porathe - Norwegian University of Science and Technology

Dr. Thomas Porathe explored the different e-Navigation services that could be supported by a marine radiobeacon communication system. This was examined through the perspective of the user rather than a purely technological point of view. It was identified through examining case studies of incidents that usability is key to any e-navigation solution including DGPS / DGNSS. A ship should stay in its ‘moving haven’, that is its expected position on a planned route at any given time. PNT integrated with other bridge systems would measure whether or not a ship

Looking back at what the aim was when starting the e-navigation work, what have we achieve so far and what lies ahead of us? There was some speculation from his vantage point of what could be expected of the future. The take-away from this speculation was: expect more traffic and less available water to sail in leading to a more constrained traffic situation. Paired with autonomous vessels, more extreme weather and an increasingly rogue environment we will be facing challenges where reliable PNT will be a cornerstone.

6.4 Question and answer session

A number of questions were asked from the floor and discussion highlighted the following:

- With reference to R-Mode at MF, the issues related to the ambiguity resolution and the impact of sky wave effects were discussed, along with potential mitigation methods, however it was noted that the legacy user must be kept in our minds going forward too.
- It was recognised that thought must be given to the future use of bandwidths currently available as it takes time to go through processes with organisations such as the ITU, should any changes be required.
- Does the model of R-Mode MF accuracies include phase errors due to antenna and ground conductivity changes? The R-Mode project is aware of the problem of phase errors particularly with changes in the weather. There is a plan to measure and monitor the change noting that the infrastructure was not built for R-Mode and it's important to confirm that every component is able to be used to support R-Mode.
- There is a possibility to run R-Mode as a hybrid as most of the time GNSS is available and when it is, we should use it.
- GNSS is evolving including the potential introduction of authentication on the Galileo and GPS open services, however it should be noted that while authentication will give protection against spoofing, GNSS will remain vulnerable to jamming.
- It was noted that there is a need to examine the methods of identifying when there is a problem and for improved safety of navigation this means getting the message out to the user when there is an issue. Consideration should be given to how this is portrayed to mariners including alerts on ECDIS or other integrated bridge control systems.
- The systems that we have now such as RAIM don't currently share any information regarding integrity in a visible way.
- A roadmap has been developed in IALA for R-Mode. Currently the map states that the system could be operational by 2030.
- Consideration should be given to the effect of ionospheric delay and the effect the sun has on it, and therefore GNSS position accuracy requirements may not be achieved in some parts of the world unless augmented.
- Navigational aids on the road such as signs or stop lights give indications to users regarding navigational behaviour however in the maritime world there is no warning to behaviour such as this as there are no indications such as light & signals etc. Consideration could be given to developing methods of communicating such intentions.
- Given the potential to move the R-Mode MF CW signals further apart in order to aid ambiguity resolution and potentially ease some of the skywave effects, it was noted that the German Aerospace Centre (DLR) has conducted simulations.
- Use the same frequency for more than one R-Mode station, how will this affect the accuracy between local clocks? We must have a standard to agree TDMA implementation, so we are accurate in the time slot. We must think about what the length of a time slot should be.

7. DEVELOPING IALA GUIDANCE

Dr. Alan Grant led the discussions regarding the structure and scope of new IALA Guidance on the future of marine radiobeacon DGPS/GNSS and began by reviewing Recommendation 135 on the Future of DGNSS. He noted that there was a lot of content in the current recommendation that has been discussed in the workshop and these topics should be carried over to the new guideline.

It was noted that IALA currently recommends members to provide DGNSS services. IALA also recommends members to keep their radio beacon infrastructure with a view of using it for other purposes such as R-Mode. Nevertheless, several members are discontinuing their DGNSS services and removing antennas and transmitter sites. It may be necessary to adjust the recommendations in order to mitigate possible liability issues for these members.

It was also noted that recommendations are technologically agnostic, and the details of technical solutions to these recommendations are in the Guidelines. The group worked upon the headings of the new guideline and added issues that should be addressed under each section. The structure of the draft guideline was agreed as follows:

1 INTRODUCTION

1.1 History of Marine Radiobeacon DGPS/DGNSS

1.2 Maritime requirements and standardisation

2 Sources of position integrity

3 Future options

3.1 Maintain GPS L1 corrections

3.2 Provide corrections to multiple GNSS and/or GNSS frequencies

3.3 Discontinue services

4 Future development

5 Key points to consider

7.1 IALA updates on DGNSS, Minsu Jeon – IALA

Minsu Jeon introduced the work of IALA regarding DGNSS with a statistics report. It was noted that there is a decrease in numbers of DGNSS stations, but this is due to the large amount of stations decommissioned by Japan and the US between 2018 and 2019. He then examined the current IALA documentation structure around the Augmentation services. The draft Guideline of the workshop output will replace IALA R135 The Future of DGNSS.

He updated the participants that NCSR 7 agreed to update the Strategic Implementation Plan (SIP) on e-Navigation at the next session in 2021, and it could be a good chance to submit a proposal of new Maritime Service on PNT and augmentation service as MS 18.

The S-24x Product Specification development on positioning was discussed with many of possible product specifications such as RAIM non availability map and position Integrity. Portrayal of positioning information on ECDIS should be discussed in the working group of ENG.

8. WRITING DRAFT GUIDANCE

After the Guidelines structure and possible content was identified the workshop divided into different groups all considering different sections of the draft. The sections were then collated on the fileshare and put together into the document by the secretary.

9. DOCUMENTATION REVIEW AND FINALISE DRAFT GUIDANCE

Participants reviewed the text that they had drafted at the workshop. Some changes were made, and it was agreed that under each section the main points that were essential to cover in the guidance would be added. The draft guideline in Annex D will be forwarded to PAP, ARM and ENG Committees for further development.

10. CLOSING OF THE WORKSHOP

10.1 Workshop review and conclusions

The workshop participants considered the various presentations that were made and through discussion it was noted that:

- IALA recognises the important need to inform the mariner, in a clear and timely manner, if GNSS becomes unreliable;

- National competent authorities should take decisions based upon the volume of traffic and degree of risk and the need to ensure that integrity information is provided;
- contemporary GNSS stand-alone services do not provide integrity information to the users;
- satellite based augmentation services (SBAS) provides system integrity information, but use the same frequency band as GNSS and are therefore equally susceptible to jamming and spoofing;
- current implementations of Receiver Autonomous Integrity Monitoring (RAIM) are considered inadequate due to the current lack of maritime specific RAIM algorithms;
- while the IALA maritime radiobeacon DGNSS concept improves positional accuracy somewhat, its main utility today is the provision of real-time integrity information;
- the IALA DGNSS concept is globally harmonised and compatible with most shipborne GNSS receivers but there is uncertain levels of use;
- the IALA DGNSS frequency allocation is recognised as a significant asset in global harmonisation;
- many DGNSS service providers are facing difficulties in continuing their services with ageing equipment requiring significant investments;
- some service providers have decided to discontinue their DGNSS services, while others have upgraded their equipment, but the majority have not made up their mind yet and are seeking guidance; and
- several different architectures are available and can modernise DGNSS implementation in a more cost effective way.

Consequently, the workshop agreed that IALA should consider:

- encouraging IALA members to ensure that GNSS integrity information is provided in their area of responsibility;
- encouraging IALA members who discontinue their DGNSS services, to seek alternative ways of informing mariners, in a clear and timely manner, if GNSS becomes unreliable; and
- identifying alternative new and innovative ways of providing GNSS integrity information to mariners and find ways to speed up their development, including:
  - harmonised maritime GNSS user integrity algorithms;
  - encourage the development of MSR test specification and its introduction on all vessels; and
  - the introduction of R-Mode and other solutions for mitigating GNSS vulnerabilities.
- how best to co-ordinate this work with other international bodies to achieve globally harmonised solutions.

Taking into consideration some of these key findings, a draft guideline was produced which can be found in Annex D. Participants produced the framework and key points to cover in each section. The draft Guideline will be forwarded to the PAP, ARM and ENG committees for further development.

10.2 Review workshop report

The report was reviewed on-screen and agreed upon.

10.3 Closing of the workshop, Omar Frits Eriksson – IALA Secretary General

Omar Frits Eriksson thanked the workshop on behalf of IALA for all their energy and hard work. There had been many important and interesting discussions that would benefit future IALA documentation regarding the future of DGPS / DGNSS services. He wished all a pleasant weekend and a safe journey home.

10.4 Closing of the workshop, Mike Bullock and Phil Day – Northern Lighthouse Board

On behalf of the Northern Lighthouse Board Mike Bullock and Phil Day congratulated participants on an enjoyable and productive workshop. He hoped that all had enjoyed their stay in Edinburgh and wished them a safe journey home.

11. SOCIAL EVENTS AND TECHNICAL VISIT

11.1 Workshop icebreaker

On Monday evening, following the workshop, participants were asked to bring some food or drink from their own country to share in the usual IALA way in the Northern Lighthouse Board Stephenson Rooms. As ever, this gathering was a great success, and all had the opportunity to taste a nip of whisky in the best traditions of Scotland.

11.2 Workshop dinner sponsored by GRAD

An enjoyable dinner generously sponsored by GRAD was enjoyed on Thursday evening at the restaurant Stac Polly. The cuisine was a modern take on Scottish classics and discussions were continued long into the night.

11.3 Technical visit, tour of HMY Britannia

Participants got to visit Her Majesty’s Yacht Britannia that is moored in Leith near Edinburgh. From the elegant State Apartments to the gleaming Engine Room the workshop got to see where Prince William and Prince Harry spent their summer holidays. Notable guests on the yacht ranged from kings and queens, world leaders and celebrities who were wined and dined; from Frank Sinatra and Liz Taylor to Nelson Mandela and Sir Winston Churchill. And of course, allegedly, there was a DGPS receiver onboard!

ANNEX A WORKSHOP PARTICIPANTS

Participant	Title	Member Country	E-mail
Mr Andrew DILLON	Australian Maritime Systems	Australia	andrew.dillon@marsys.com.au
Mr Mahdi AL MOSAWI	Middle East Navigation Aids Service (MENAS)	Bahrain (Kingdom of)	mahdi@menas.com.bh
Mr Guilherme PEREIRA	Diretoria de Hidrografia e Navegação of the Brazilian Navy, Brazil	Brazil	gblack.mb@gmail.com
Ms Caroline HUOT	Canadian Coast Guard	Canada	caroline.huot@dfo-mpo.gc.ca
Prof Manuel LOPEZ MARTINEZ	European GNSS Agency (GSA)	Czech Republic	manuel.lopezmartinez@gsa.europa.eu
Mr Joergen ROYAL PETERSEN	Danish Maritime Authority	Denmark	jrp@dma.dk
Mr Jan THORN	Danish Maritime Authority	Denmark	jat@dma.dk
Mr Mohamed ESSA	Egyptian Authority for Maritime Safety	Egypt	mohamedessa8080@gmail.com
Mr Tiit PALGI	Estonian Maritime Administration	Estonia	tiit.palgi@vta.ee
Ms Kaisu HEIKONEN	Finnish Transport Infrastructure Agency	Finland	kaisu.heikonen@ftia.fi
Mr Xavier HERNOË	Direction des Affaires Maritimes	France	xavier.hernoe@developpement-durable.gouv.fr
Mr Pierre-Yves MARTIN	CEREMA	France	pierre-yves.martin@cerema.fr
Mr Omar Eriksson	IALA	France	omar.eriksson@iala-aism.org
Mr Minsu Jeon	IALA	France	minsu.jeon@iala-aism.org
Mr Thomas Southall	IALA	France	tom.southall@iala-aism.org
Mr Tobias EHLERS	Federal Maritime and Hydrography Agency (BSH)	Germany	tobias.ehlers@bsh.de
Mr Michael HOPPE	Federal Waterways & Shipping Administration	Germany	michael.hoppe@wsv.bund.de
Mr Thomas Horvath	Alberding GMBH	Germany	horvath@alberding.eu
Mr Stefan Gewies	DLR	Germany	Stefan.Gewies@dlr.de
Mr Julian LANCASTER	International Maritime Pilots Association (IMPA)	IMPA	office@impahq.org
Mr Ronan BOYLE	Commissioners of Irish Lights	Ireland	ronan.boyle@irishlights.ie
Mr Angus SCOTT	Wartsila	Ireland	angus.scott@wartsila.com
Mr Stan STAMPER	Wartsila	Ireland	stan.stamper@wartsila.com
CDR Hideki NOGUCHI	Japan Coast Guard	Japan	hideki.noguchi@gmail.com
Mr Roslee MAT YUSOF	Light Dues Board Peninsular Malaysia, Marine Department	Malaysia	roslee@marine.gov.my
Mr Ramli MOHD	National Hydrographic Center	Malaysia	ramli4550@gmail.com
Mr Stig Erik CHRISTIANSEN	Kongsberg Seatex AS	Norway	stig.erik@kongsberg.com
Mr Bjornar KLEPPE	Norwegian Coastal Administration	Norway	bjornar.kleppe@kystverket.no
Mr Cato Eliassen	Kongsberg	Norway	cato.eliassen@km.kongsberg.com

Mr Thomas Porathe	NTNU	Norway	thomas.porathe@ntnu.no
Mr Marek DZIEWICKI	Maritime Office Gdynia	Poland	marekdz@umgdy.gov.pl
Mr Jan MLOTKOWSKI	Maritime Office in Gdynia	Poland	jan.mlotkowski@umgdy.gov.pl
Mr Hyun KIM	Ministry of Oceans and Fisheries	Republic of Korea	nox88@korea.kr
Mr Sak LEE	Ministry of Oceans and Fisheries	Republic of Korea	issac1015@korea.kr
Ms Sul Gee PARK	Korea Research Institute of Ships & Ocean Engineering (KRISO)	Republic of Korea	sgpark@kriso.re.kr
Dr Sang-Hyun PARK	Korea Research Institute of Ships & Ocean Engineering (KRISO)	Republic of Korea	gnss.spark@gmail.com
Gillian BURNS	NLB	Scotland	gillianb@nlb.org.uk
Peter DOUGLAS	NLB	Scotland	peterd@nlb.org.uk
Phil Day	NLB	Scotland	phild@nlb.org.uk
Mr Jaime ALVAREZ VELASCO	ESSP-SAS	Spain	jaime.alvarez@essp-sas.eu
Mr Javier ARGUL MARIN	Puertos del Estado	Spain	fjargul@puertos.es
Ms Ana CEZON	GMV Aerospace and Defence S.A.U	Spain	acezon@gmv.com
Mr Ginés MORENO	GMV Aerospace and Defence S.A.U	Spain	gimoreno@gmv.com
Mr Juan Francisco REBOLLO	Puertos del Estado	Spain	jfrebollo@puertos.es
Mr Jesper BACKSTEDT	Swedish Maritime Administration	Sweden	jesper.backstedt@sjofartsverket.se
Captain Roger BARKER	Trinity House	UK	roger.barker@trinityhouse.co.uk
Commodore Robert DOREY	Trinity House	UK	rob.dorey@thls.org
Mr Alan Grant	GRAD	UK	Alan.Grant@gla-rad.org
Mr Martin Bransby	GRAD	UK	Martin.Bransby@gla-rad.org
Mr Chris Hargreaves	GRAD	UK	Chris.Hargreaves@gla-rad.org
Mr David Patraiko	Nautical Institute	UK	djp@nautinst.org

ANNEX B SPEAKER BIOGRAPHIES

Mike Bullock: Welcome to Northern Lighthouse Board

Mike Bullock joined the Northern Lighthouse Board in 2014 as Chief Executive after 34 years in the Royal Navy. During his naval career he served in a total of six ships and submarines, as well as working ashore in the Ministry of Defence, NATO, the UK Embassy in Washington DC and in the Pentagon. He is a Director of the Scottish Maritime Cluster which brings together Scotland's world-class shipping, ports, shipbuilding, equipment, education, training and maritime service enterprises to drive economic growth in the global maritime market.

Dr. Alan Grant: History of marine radiobeacon DGPS/DGNSS

Dr Alan Grant is a Principal Radionavigation Engineer for the General Lighthouse Authorities of the UK and Ireland's Research and Development team (GRAD). He chairs the radionavigation services working group within the IALA ENG Committee. Alan is a Fellow, and a Vice President, of the Royal Institute of Navigation, a member of US Institute of Navigation, a Chartered Engineer and a Chartered Physicist.

Peter Douglas: Maritime requirements and standardisation position

Peter joined Northern Lighthouse Board in 1993 after a short service commission in the Royal Navy. After 10 years as the board's Radio Engineer, he moved to the role of Navigation Manager, responsible for AtoN planning and also policing of all AtoN providers in Scotland and the Isle of Man. Peter joined the IALA RNAV in 1998 and subsequently chaired it's GNSS Working Group. He was a member of the ENAV Committee 2006-18, chairing the PNT WG for five years. Since 2018 he has been a member of the ANM Committee. He holds an MSc in Navigation Technology and an IALA Level 1 Managers' Certificate, and is a Fellow of the Royal Institute of Navigation.

Michael Hoppe: Marine radiobeacon DGPS/DGNSS and View of authority opting to provide multi-constellation augmentation

Michael Hoppe received his diploma as a radio engineer in 1990. Since 1991 he has been working for the Traffic Technologies Centre within the German Federal Waterways and Shipping Administration. He is responsible for the field of radio navigation systems for maritime and inland waterways applications. Michael Hoppe is a member of various national and international working groups dealing with development and standardisation of integrated PNT systems. Since 1998 he has been a member of the IALA in various technical committees. At present he is acting as vice chair of the PNT WG within the IALA Engineering Committee.

Chris Hargreaves: Receiver Autonomous Integrity Monitoring

Chris has been with the GLA for 10 years and started as a Navigation Cadet on ships before moving into research. He worked on the eLoran projects for a long time, developing data collection, processing and integrity algorithms. Chris' work is mainly the mathematical / data processing / algorithm side of things plus system coverage modelling and simulation.

Manuel Lopez: Satellite Based Augmentation Systems

Prof. Dr. Manuel Lopez Martinez is Technology Officer in the European GNSS Agency (GSA), where he is supporting and fostering the adoption of Galileo and EGNOS in maritime, inland waterways and search and rescue applications. He received his PhD in System Engineering and Automation from the University of Seville in 2005. He got a permanent position as associate professor at the University of Seville in 2008, where he was teaching until he joined the GSA in 2013 as seconded national expert in the Market Development Department.

Angus Scott: Commercial Services

Angus Scott represents Wärtsilä, the global vessel equipment manufacturer, although he originally trained as a hydrographic surveyor with an extensive history in the precise GNSS positioning industry dating back to the early 1990's. A career that began with several years working offshore with Racal Survey developed into managing the African fleet of Offshore Support Vessels for Seacor Marine. He eventually became Vice President of the second-largest precise GNSS supplier to the global marine market, Veripos, before joining Wärtsilä.

Tamás Horváth: View of the DGPS infrastructure provider

Tamás Horváth obtained an M.Sc. degree in Surveying and Geoinformatics from the Budapest University of Technology and Economics in 2002. He has long years of experience in the development and operation of GNSS ground based augmentation systems. He worked as a GNSS specialist at Thales GeoSolutions (UK) and was involved in the development and support of SkyFix XP, a global PPP service used in precise off-shore positioning. From 2004 Tamás spent 8 years at FÖMI, the Hungarian surveying and mapping authority, as head of the national GNSS Service Centre, being responsible for the establishment and operation of the nationwide RTK network and the precise positioning services offered to surveyors and precision agriculture users.

In 2012 he joined Alberding GmbH in Germany, where he is currently Technical Sales Manager, responsible for the sales and support of GNSS infrastructure solutions in the precision agriculture, surveying and inland waterway navigation sectors.

Cato Giil Eliassen: View of the DGPS infrastructure provider

Cato Giil Eliassen has the role as Product Manager for the business area Navigation and Infrastructure in Kongsberg Seatex. In the period stretching from 2002 to 2015 he was a Project Manager mainly working with AIS and DGPS infrastructure projects around the globe. He was educated at the Norwegian University of Science and Technology (MSc) and at the RNoN Naval Academy. He served in the Norwegian Navy for nine years.

Tobias Ehlers: View of the receiver manufacturer

Dipl.Ing. electrical engineering (RF-Communication)

Places of education: Univ. of applied Sciences Luebeck, Danmarks Designskole Copenhagen, Diploma at Rohde & Schwarz Munich

Started at BSH in 2003 as lead engineer for maintenance and development of the German unmanned marine measurement network in the North- and Baltic Sea.

Since 2005 he has been an engineer in the BSH type approval lab (EPFS equipment), nominated EPFS (GNSS) expert for the work in IMO (PNT Guideline) and IEC working groups and coordination and participation in research projects in the EPFS domain.

Juan-Francisco Robello: View of authority opting to re-broadcasting 3rd party corrections

Since July 2001 Juan-Francisco Rebollo is Head of the Spanish Marine Aids to Navigation Service in Puertos del Estado, the Spanish competent authority in this matter. He joined Puertos del Estado in 1993, as Head of the Technical Center of Marine Signals.

Degree in Physical Sciences, from the University of Madrid, Master in Port Management and Intermodal Transport, from the University of Comillas, he has completed higher courses in Project Management, Environmental Engineering and Quality Management.

Related to PNT systems, he has the project manager of the Spanish DGPS Network for Marine Navigation project from more than 15 years and is leading the reengineering project of that network, he has also participated in the SC-24 project for the evaluation of EGNOS as a positioning system in the maritime sector.

Vice-president of the Spanish Lighthouses Commission and during the period May 2014 to May 2018 he has been President of the International Association of Marine Aids to Navigation and Lighthouses Authorities (IALA) and from June 2019 is Honorary Member of IALA.

NOGUCHI Hideki: View of authority opting to discontinue services

Hideki was sent to the USCG as part of the short-term Japanese government fellowship for the buoy management study in 1994. Following this he was also sent to the Philippine Coast Guard as a technical expert for safety of navigation and SAR in 2005 and 2006. He was appointed as the chair of the IALA ENAV committee in 2017 and is currently the representative of the Japanese delegation to IMO MSC and NCSR.

Stefan Gewies: High level discussion on potential considerations and options (hardware, frequency assignment benefits)

Stefan Gewies is a scientist working for the German Aerospace Center in the Institute of Communications and Navigation. He is there Head of the Working Group Maritime Services of the Department of Nautical Systems and Project Manager of an international project that aims to build an R-Mode testbed in the Baltic Sea. His current research focus is on terrestrial maritime navigation systems using signals-of-opportunity. Stefan is a member of the Radionavigation Services Working Group of the IALA ENG Committee.

Dr. Sang Hyun Park: Korean positioning system and R-Mode

Dr. Sang Hyun PARK is a director of Marine PNT Research Centre at the Korea Research Institute of Ships & Ocean Engineering (KRISO). The Marine PNT Research Centre is in charge of research and development of maritime PNT-related research projects promoted by the South Korean government, and serves as a technical advisor for the government to establish technical policies. He has been involved in lots of radio navigation-related research projects such as a vessel berthing system using GNSS, DGNSS reference stations and integrity monitors, eLoran system, etc. His current research interests focus on resilient PNT systems for maritime safety.

Bjørnar Kleppe: View of authority currently undecided on the future of its services

Bjørnar Kleppe is an adviser in the Maritime Safety Department in the Norwegian Coastal Administration and his responsibilities include radio navigation.

Dr. Thomas Porathe: Potential E-Navigation services

Dr Thomas Porathe is professor of interaction design at the Norwegian University of Science and Technology in Trondheim, Norway. He has a PhD in Information Design and is specialising in maritime human factors and design of maritime information systems. He has been working with e-Navigation since 2006 in EU-projects like BLAST, EfficienSea, MONALISA, ACCSEAS, SESAME and unmanned ship projects like MUNIN, IMAT, HUMANE and LOAS. He is participating in the work in IALA's ARM committee.

M**insu Jeon: IALA updates on DGNSS**

Minsu Jeon is the Technical Operations Manager at IALA. He is responsible for supporting and coordinating the work of the committees and representing the association in a technical capacity. Minsu is an Aids to Navigation Manager and has served in the Korean Navy. Minsu worked as the Regional Safety Navigation Adviser in the Pacific Community (SPC). There, he contributed to enhancing the level of safety in the Pacific region. Prior to 2016, Minsu worked with Korea Institute of Aids to Navigation which is a public organisation of Korea.

Martin Bransby: View of authority opting to discontinue services

Martin Bransby is the Head of Research and Development at the General Lighthouse Authorities of the UK and Ireland (GLA). He is responsible for the delivery of the GLAs research, innovation and development programme in areas such as resilient position navigation & timing, AIS, e-Navigation, GNSS and their augmentations, visual signalling and for the development of GLA policy and strategy. He is a Chartered Engineer, Fellow and Council member of the Royal Institute of Navigation, and holds memberships of the Institute of Engineering & Technology, Institute of Marine Engineering, Science & Technology and the US Institute of Navigation. He is also a member of the International Marine Aids to Navigation and Lighthouse Authorities' Aids to Navigation Requirements & Management Committee, where he co-chairs the working group on Information Services and Portrayal.

ANNEX C TECHNICAL PROGRAMME

DAY 1 – Monday, 27th January 2020 - Workshop on DGPS/DGNSS

Time	Activity	
1300 – 1400	Registration & lunch (provided)	
1400 – 1520	**Session 1 – Opening of the Workshop**	**Chair: Phil Day, Chair of IALA ARM Committee**
5 min	Welcome	Mike Bullock
10 min	Welcome from IALA	Omar Frits Eriksson
5 min	Administration and Safety Briefing	Phil Day
20 min	Working programme of the week and expectations	Phil Day
20 min	History of marine radiobeacon DGPS/DGNSS	Alan Grant
20 min	Maritime requirements and standardisation position	Peter Douglas
1520 – 1530	Group photo	
1530 – 1600	Break	
1600 – 1740	**Session 2 - Sources of position integrity**	**Chair: Alan Grant**
20 min	Marine radiobeacon DGPS/DGNSS	Michael Hoppe
20 min	Receiver Autonomous Integrity Monitoring	Chris Hargreaves
20 min	Satellite Based Augmentation Systems	Manuel Lopez Martinez
20 min	Commercial services	*TBC*
20 min	Q/A session	Alan Grant
1740– 1900	**Workshop Icebreaker (Bring something from your own country to share in the IALA way)** Venue: Northern Lighthouse Board Stephenson Rooms	

DAY 2 – Tuesday, 28th January 2020 - Workshop on DGPS/DGNSS

Time	Activity	
0900 – 1130	**Session 3 – Views and opinions**	**Chair: Phil Day**
10 min	Welcome to the day	Phil Day
30 min	View of the mariner	David Patraiko
30 min	View of the DGPS infrastructure provider	Cato Giil Eliassen & Jurgen Alberding
1010-1030	Break	
30 min	View of the receiver manufacturer	Tobias Ehlers
30 min	Q&A session	Phil Day
1130 – 1650	**Session 4 – Case studies**	**Chair: Alan Grant**
30 min	View of authority opting to maintain current service (GPS L1)	Alan Grant
30 min	View of authority opting to provide multi-constellation augmentation	Michael Hoppe
1230 – 1300	Lunch (on own – lots of local lunch options)	
30 min	View of authority opting to re-broadcasting 3rd party corrections	Juan Francisco
30 min	View of authority opting to discontinue services	Hideki Noguchi & Martin Bransby
30 min	View of authority currently undecided on the future of its services	Bjornar Kleppe
1430 – 1500	Break	
90 min	Q&A session	Alan Grant
20 min	Review of the day	Phil Day
1650 onwards	Free time on your own	

DAY 3 – Wednesday, 29th January 2020 - Workshop on DGPS/DGNSS

Time	Topics	
0900 - 1115	**Session 5 – Future hardware options**	**Chair: Michael Hoppe**
30 min	High level discussion on potential considerations and options (hardware, frequency assignment benefits)	Stefan Gewies
30 min	- Korean positioning system & R-Mode	Sanghyun Park
30 min	- Potential E-Navigation services	Thomas Porathe
1030 – 1045	Break	
30 min	Q&A & brainstorming session	Michael Hoppe
1115 – 1230	**Session 6 – Developing IALA Guidance**	**Chair: Alan Grant**
45 min	Develop outline structure and scope of new IALA Guidance on the future of marine radiobeacon DGPS/GNSS.	
1230 – 1330	Lunch (on own – lots of local lunch options)	
1330 – 1730	**Session 7 - Writing draft guidance**	**Chair: Alan Grant**
5 min	Overview of the approach	
105 min	Continue development of guidance development, moving from defining structure to writing content. - May split into smaller drafting groups to work on different parts of the IALA Guideline & Recommendation (if needed).	
1515 – 1545	Break	
105 min	Continue development of guidance development, moving from defining structure to writing content. - May split into smaller drafting groups to work on different parts of the IALA Guideline & Recommendation (if needed).	
1730 onwards	Free time on your own	

DAY 4 – Thursday, 30th January 2020 - Workshop on DGPS/DGNSS

Time	Activity	
0900 – 1200	**Session 8 – Finalise draft guidance**	**Chair: Alan Grant**
90 min	Complete draft Guideline in drafting groups	
1030 – 1100	Break	
60 min	Complete draft Guideline in drafting groups (Deadline to submit draft sections of the GL by 1200)	
	Plenary	
1200 – 1230	Lunch (on own – lots of local lunch options)	
1230 – 1730	**Technical visit**	**Chair: Phil Day**
	Technical visit, tour of HMY Britannia	
1900	**Workshop Dinner (sponsored by GRAD)** Venue: Stac Polly (29-33 Dublin St. EH3 6NL) Dress code: casual	

DAY 5 – Friday, 31st January 2020 - Workshop on DGPS/DGNSS

Time	Activity	
0900 – 1100	**Session 9 – Documentation review**	**Chair: Alan Grant**
120 min	Review final draft and agree submission to ARM and ENG	
1100 – 1130	Break	
1130 – 1230	**Session 10 – closing**	**Chair: Phil Day**
45 min	Workshop review and conclusions Review workshop report - Chairs/Rapporteurs review main points of each session - Report findings agreed on screen	Phil Day Minsu Jeon
10 min	Closing of the workshop	Omar Frits Eriksson
5 min	Closing of the workshop	Phil Day

ANNEX D **DRAFT GUIDELINE ON THE FUTURE OF MARINE RADIOBEACON DGPS/GNSS**

List of Tables

List of Figures

List of Equations

1. INTRODUCTION

IALA radiobeacon services have been operating for many years, providing a harmonised service in many parts of the World. However, many administrations are now considering the on-going requirement for the service and as such whether to update ageing equipment. Changes in technology mean administrations [have to] face choices on the way forward which include retaining the same functionality [or recapitalisation], introducing new technology or discontinuing the service [discontinuing the radiobeacon service].

This document aims to provide guidance to national administrations on which aspects and questions to consider when assessing the future of the service. It provides an overview of available options and other aspects which may assist in the decision process.

1.1 HISTORY OF MARINE RADIOBEACON DGPS/DGNSS

The IALA DGNSS beacon system was developed in the 1990s and systems were installed in many countries over the period 1991-2000. The system was adopted as the international maritime standard for providing differential corrections for Global Navigation Satellite Systems (GNSS).

Marine radiobeacon DGPS was first developed to counter Selective Availability (SA), a deliberate error added to the civilian GPS service to degrade accuracy for civilian users, but which the United States discontinued in May 2000. As such, the original driver was accuracy improvement, however since SA's removal in most locations the main issue to be addressed is integrity however the accuracy improvement remains important for some users.

While IALA supports the use of radiobeacon DGNSS where considered appropriate by the national competent authority under SOLAS and as such it is not provided everywhere.

1.2 MARITIME REQUIREMENTS AND STANDARDISATION

IMO Resolutions A.915 (22) [ref] and A.1046(27) [ref] provide maritime performance requirements, albeit it is recognised that A.915 is in need of review and update. Maritime beacon requirements are consolidated in IALA Guideline No. 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz [ref].

It is recognised that today's stand-alone [un-augmented] GNSS are often sufficient to meet all but the most stringent accuracy requirements listed in Resolution A.915 and A.1046, the open services provided by the constellation GNSS service do not provide integrity information to the user. However they are not able to meet the integrity requirement taking into account the risk within these resolutions.

IMO receiver performance standards and the IEC receiver test specifications make provision for the use of marine radiobeacon DGNSS and Receiver Autonomous Integrity Monitoring (RAIM). While mentioned in the IMO receiver performance standards, marine radiobeacon DGNSS is not a carriage requirement. However, some classification societies require a DGPS receiver for certain classes.

IALA recognises the important need to inform the mariner, in a clear and timely manner, if GNSS become unreliable. This guideline considers different options that can support this by providing integrity at system level or user level. The differences between these integrity levels can often confuse and to aid understanding further information on integrity is captured in Annex X.

Most shipbourne receivers fitted today are radiobeacon DGPS enabled with many also capable of using SBAS information. There is, however, no SBAS type approval currently in place and therefore mariners should exert caution on the use of SBAS with non-approved receivers.

When assessing vessel operations the age of navigation equipment onboard a vessel must be a considered. It is recognised that bridge equipment will only be updated to the latest IEC standard when the ship owner considers it necessary and as such, the equipment may not be providing the latest functionality.

2. SOURCES OF POSITION INTEGRITY

2.1 CONVENTIONAL NON-SATELLITE BASED NAVIGATION

SOLAS Chapter V Chapter 19 specifies carriage requirements for shipborne navigation systems and equipment. The requirements are based on tonnage and build date and therefore apply to existing vessels, with each item being associated with the relevant IMO performance standards.

This includes: gyro/magnetic compass, speed log, echo sounder & radar. In this context, we can consider the use of these systems as conventional navigation.

All vessels should be navigated by using all available means, which includes the use of both conventional and additional equipment (where specified) such as ECDIS and GNSS. All these systems have potential errors and tolerances and should be cross checked with other equipment. STCW ECDIS training requires cross checking of position with additional manual position fixes such as by visual bearings or radar. Other methods of verifying position include parallel index on radar and visual situation awareness from observing navigation marks adjacent to the vessel, such as a buoyed channel, lighthouse, sector lights or significant navigational features.

2.1.1 HOW DOES CONVENTIONAL NAVIGATIONS ASSIST WITH IDENTIFYING A GNSS INTEGRITY ISSUE

In accordance with best practice, integrity monitoring of all systems is an intrinsic element of the process of navigation. A fault could emerge in the gyro compass as readily as the ECDIS or GNSS system.

A GNSS integrity issue would be highlighted by a difference in position obtained by conventional means when compared with a position obtained by GNSS. A fix could be obtained by visual compass bearings, radar ranges and bearings, parallel index techniques, visual observations, depth from echo sounder, DR and EP. Traffic flow, buoyage, ferry routing, fishing vessel concentrations, windfarm locations, oil rigs and offshore structures are all factors to be taken into account under the heading of good seamanship and situational awareness.

2.1.2 NEW AND EMERGING BRIDGE EQUIPMENT.

Multi-constellation receivers: In addition to GPS, further GNSS constellations have been established which are in some cases, being integrated within a single receiver unit. This has advantages and disadvantages for the mariner. In one respect, the mariner now has even more information to process and manage, while from a different perspective, there is now a greater opportunity to verify position integrity by comparing positions obtained from different constellations , recognising that such comparison will identify single constellation failures and not external influences such as jamming. The origin of the position data and the output position provided to the user needs to be very clear.

2.1.3 ADVANTAGES OF CONVENTIONAL NAVIGATIONAL PRACTICE

For SOLAS vessels, the equipment is mandated and type approved and therefore guaranteed to be available to the mariner with a specified performance standard.

Training is mandated through STCW and therefore all bridge personnel are comprehensively trained in the operation of these core systems and techniques. Training in GNSS denial techniques is recommended.

These onboard tools are independent of external networks or radio signals. They are therefore less susceptible to interference, jamming or cyber attack.

2.1.4 DISADVANTAGES

Skills and Training: The skills required to navigate by conventional means are built up over time and through formal STCW qualifications. There is evidence to suggest that bridge teams can become over reliant on GNSS, particularly when coupled with ECDIS, leading to skill fade and a lack of opportunity to practice conventional navigation techniques. Despite cross referencing being formally mandated within ECDIS training, failure to consistently follow procedures will mean that an error in GNSS will not be immediately identified.

Not all vessels will be fitted with ECDIS, but virtually all will have GPS and many will have ECS, with various levels of training, standardisation and charting. The need for a thorough approach to navigation remains in all cases, including cross referencing position fixing systems, particularly where GNSS is used as the primary means.

2.1.5 Differences in equipment

Many mariners frequently change from ship to ship and company to company. Manufacturers present information in different ways and unfamiliarity with the equipment may mean that the mariner may not recognise an alarm or indication when it occurs even when a GNSS unit itself is advising of an integrity issue. This could be a RAIM indication or some other failure and applies similarly to ECDIS and other navigation equipment.

Note: ECDIS is not mandated for existing cargo ships of less than 10,000 grt, though many vessels will have ECS. Fishing vessels and small leisure craft will have a variety of often non-type approved equipment.

2.2 MSI

All ships are required to use type approved equipment neccessary to receive navigational warnings and Notices to Mariners issued by authorities. Whenever disturbances to GNSS occur, have not been warned through NtoM, and are significant, users will report (required to report? SOLAS?) this to VTS or coastal radio stations, assessed by the MSI-authority and navigational warnings is issued. The delay between the occurrence of disturbances and the issuance of a navigational warning is unpredictable. In most cases such warnings will be delayed several hours and only disturbances that have major impact on ships navigation can be expected to be reported. Warnings are useful only if the disturbances are still occuring after the warning has been received. Additional systems used by authorities to monitor GNSS performance in the sea area may be utilized to detect disturbances and issue more precise navigational warnings with shorter delay. Navigational warnings include all ships and coverage is not limited. It is expected that delays in provision of navigational warnings will be reduced in the future as this service is part of the IMO E-navigation concept. Exact timelines for this is however uncertain.

NtoM provide advance warning of loss of integrity of GPS signals occuring from pre-planned acivities such as military excercises.

2.3 SBAS

SBAS improves the accuracy and reliability of GNSS by correcting signal measurement errors and by providing information about the accuracy, integrity and availability of GNSS signals as identified in IALA Guideline 1152 considering the SBAS Maritime Service SiS and

Originally SBAS was developed for aviation users; their use in the maritime domain is increasing enhancing the marine safety for harbour approaches and coastal navigation. IMO recognize GNSS as part of WWRNS only for ocean areas where required performance levels can be achieved without using augmentation systems [e.g. IMO Circular SN.1/Circ.329]. In order to achieve the levels of performance required in IMO Resolution A.1046(27) for coastal areas and harbour approaches, augmentation of GNSS is needed.

The introduction of SBAS corrections tailored to the mariners could follow a short and a medium time approach so as to complement the DGNSS network:

- The short term solution for providing EGNOS corrections to mariners is identifies in IALA G1129 the Retransmission of SBAS corrections using MF-Radiobeacon and AIS.
- The medium term solution is developing the SBAS Maritime Service Signal in Space (SiS) according to IMO Res.1046 Operational Requirements. At the time of writing this Guideline, the SBAS Maritime Service is under development.

A long term SBAS Maritime Service is under definition which considers the Operational requirements of IMO Res.915, multi-frequency and multi-constellation.

IMO Resolution A.1046(27) requires that governments or organizations owning and operating the recognized radionavigation systems should state formally that the system is operational and available for use by merchant shipping. Some Governments owning SBAS as the European Commission, Australia or recently the Republic of Korea are supporting the operational use of SBAS in the maritime areas. IALA is developing an approach that will allow augmentation service providers to recognise a maritime user and encourage Governments in this recognition.

The development of the tailored SBAS service SiS for the maritime community includes:

- The definition of a Service Provision Scheme considering the roles and responsibilities of each stakeholder involved.
- The development of a Service Provision layer providing MSI related to the SBAS service performances degradations.
- The development of the SBAS type-approved receiver which considers SBAS satellite selection criteria.

The SBAS service coverage area for the maritime user should be notify by the SBAS competent government or organisation.

2.4 RTK AND PPP

Real-Time Kinematic (RTK) and Precise Point Positioning (PPP) are ground-based high accuracy GNSS augmentation systems that have been used in surveying applications for many years.

RTK is a short-range relative positioning technique providing centimetre-level accuracy based on the common processing of code and carrier phase measurements collected at reference station and user site. National surveying and mapping authorities and private companies operate RTK networks in many countries around the world. RTK correction information is usually distributed to users via VHF/UHF radio modems or through mobile Internet.

PPP is a global positioning technique that requires real-time precise satellite orbit and clock corrections derived from a globally distributed geodetic network of GNSS reference stations. PPP provides absolute positioning at centimetre to decimetre accuracy level without local reference station as used in RTK. PPP service providers broadcast corrections to subscribed users via geostationary communication satellites or the Internet.

RTK and PPP were originally developed without integrity focus. However, maritime applications such as dredging, docking, harbor maneuvers or port approach requiring high accuracy can now rely on RTK and PPP to also provide them with integrity in two ways.

One way is by providing redundant measurements, where the user's position can be simultaneously determined based on independent correction sources. Thus the correctness of the trusted vessel position can be validated.

The other way is through additional dedicated integrity messages derived from the RTK or PPP ground infrastructure. Satellite and position integrity flags can be transferred to the users along with the corrections.

For example, AIS/VDES Application Specific Messages incorporating RTK/PPP integrity information have already been defined and used in research projects. Standardisation of such novel messages is underway.

References

RD-01 RTCM 10402.3 RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.3 with Amendment 1 (May 21, 2010)

RD-02 RTCM 10403.3, Differential GNSS (Global Navigation Satellite Systems) Services - Version 3 (October 7, 2016)

RD-03 NAVGUIDE 2018 Marine Aids to Navigation Manual

RD-04 IALA Guideline 1127 Systems and services for high accuracy positioning and ranging

2.5 RADIOBEACON

- For more information on radiobeacons please see the IALA Worldwide radionavigation plan.
- The Integrity Monitor part of the system monitors the health status of satellites and MBDGPS broadcast signals as well as signal content (the accuracy of DGPS Reference Station-generated corrections). When monitored parameters exceed specified thresholds, the Integrity Monitor will generate appropriate alarms.
- The digital correction signal (containing differential corrections and integrity data) is broadcast locally over ground-based transmitters of, typically up to a 200 NM range. These transmitters operate at long/medium wave radio frequencies between 283.5 kHz and 325 kHz.
- MBDGPS services have been implemented and in existence for over 20 years and continue to provide position corrections to the mariner in some of the busiest and most used waterways in the World; however, since selective availability was set to zero in 2000, in most regions single frequency GPS can now provide sufficient position accuracy to meet all but the most stringent IMO accuracy requirements ref. Resolutions A.1046 and A.915. GNSS do not however, provide integrity in their own right: this is where MBDGPS is still a good source of real time system level integrity for maritime users.

Implementation details are available in Guideline 1112 and 1129.

The beacon service is supported by the IMO as a harmonised solution with an agreed spectrum. See Recommendation 121.

2.6 RAIM

- Introduction.

GNSS do not broadcast any information about the integrity of their signals. It is possible for a GNSS satellite to broadcast incorrect information that will cause errors on the users position, but there is no way for the receiver to determine this using standard techniques. RAIM uses redundant information to produce several GNSS position fixes and compare them, and a statistical function determines whether a fault can be associated with any of the signals. That is, when more satellites are available than needed to produce a position fix, the extra pseudoranges should all be consistent with the computed position. A pseudorange that differs significantly from the expected value may indicate a fault of the associated satellite or another signal integrity problem (e.g., Ionospheric interference).

RAIM as a term does not refer to a single algorithm or type of algorithm, there are several RAIM implementations based in different hypotheses.

There are nominally two types of RAIM, namely:

- Measurement Rejection Approach (MRA): MRA use Fault Detection and Exclusion (FDE) techniques to ensure that only valid measurements are used in the navigation solution and the respective protection levels computation.
- Error Characterisation Approach (ECA): It consists on computing Protection Levels (PLs) based on the characterization of the measurement errors; these techniques do not necessarily require FDE techniques.
- RAIM in maritime. RAIM was developed for aviation GNSS receivers and although RAIM algorithms are implemented almost universally in maritime GNSS receivers, there is currently no IMO or IEC specifications or standards which say how RAIM should operate in the maritime environment. There is therefore a need for the development of maritime specific RAIM algorithms, as RAIM algorithms developed for aviation are not suitable for the maritime environment.

Open questions on RAIM:

- There was general consensus that the RAIM standards are currently not adequate and should be developed in IMO. It would require an IMO request for a defined algorithm before the IEC is able to develop one, therefore there maybe a role for IALA to provide a suitable request.
- There was a discussion regarding the differences between maritime and aeronautical RAIM which concluded that the RAIM algorithms are generally similar, but the operational environment is already defined for aviation, but there is significant work required to understand the maritime operational environment (noise, multipath etc) which would need to be considered in the definition of a suitable algorithm.
- It was further noted that the evolution of maritime user requirements could lead to changed in the algorithm used. Currently algorithms are designed to identify single failed satellites, however with the move to multi-constellation receivers, a new algorithm may be needed to ensure efficient use of all available satellites and frequencies. Advanced RAIM and maritime M-RAIM were mentioned as future developments.
- Review all of the different sources of integrity information, provide details of their services, coverage areas, performance, timeline of availability/changes, degree of usage, pros and cons etc. list any open questions.

2.6.1 Main RAIM features

The term Classical RAIM refers to fully autonomous algorithms which can implement only one, a combination or all the following capabilities: Fault detection, Fault exclusion and Protection Level computation. Depending on the selected algorithm, its capabilities and assumptions it has different advantages and drawback. Currently the majority of RAIM algorithm implemented in maritime receivers are based on the classical aviation approach, which are bases in some hypothesis that may be not suitable for maritime domain. The following list summarises the main advantages and drawbacks that classical RAIM algorithms have:

- **Advantages**
  - It provides integrity worldwide. Since the algorithm is implemented in the user receiver and does not need (most of them) any external information they could provide integrity information to the user anywhere, if the algorithm hypothesis are met.
  - It does not necessarily require external infrastructure.
  - It provides integrity at user level if environment is well characterised. Both main RAIM families requires a correct characterization of the error components or detection thresholds to really provide integrity.
- **Drawbacks**
  - The Classical RAIM algorithms do not handle several simultaneous faulty measurements. The use of more than a single constellation will have a positive impact on positioning performance. However, with an increased number of satellites, the number of faults that need to be considered increases as well to ensure the same integrity level. Therefore, as RAIM considers nominal conditions, the probability of multiple simultaneous failures might be not neglected in the case of using two or more constellations and it needs to be reflected in the integrity risk allocation.
  - RAIM algorithms provides generally poor performances. They are based in a priori information about the error components or the environment. They must be conservative in order to provide the integrity required for any user under any condition, which imply poor performances for very conservative estimations or a safety risk if the characterisation is deficient. Moreover, this values are fixed in conventional RAIM so cannot be updated. A classic example of conservative fixed parameter is the ionospheric estimation which is provided in Classical GPS RAIM implementations by the Klobuchar ionospheric model. Although this model works very well under normal ionosphere conditions, it is not really accurate under severe ones.

- Error overbounding models shall be well characterized for maritime environment to provide the integrity required. Almost every RAIM algorithm are based in overbounding error models for their calculations, if these models are not well characterised it may imply a safety risk.
- The Classical RAIM algorithms do not handle constellation failures. Oldest RAIM algorithms does not consider this issue since they assumes that only one constellation is used. However, this limitation is overcame by several RAIMs nowadays.
- The Classical RAIM algorithms do not handle nominal error biases. It is assumed that fault-free measurements are Gaussian-distributed and their mean is zero except the faulty measurement. Nevertheless, this limitation is also overcame by several new RAIM algorithms nowadays.

- **<u>Future evolutions</u>**
  - Ad-hoc RAIM algorithm may be designed for maritime.
  - Future maritime RAIM algorithms shall be robust against hazardous local events and shall handle multiple and constellation failures.
  - RAIM algorithms requirements and validation tests shall be standarised.
  - The limitations of single failure assumption and the poor performances may be overcame with some new RAIM algorithms or the use of augmentation systems (SBAS, DGNSS, etc.)

2.6.2 RAIM IN MARITIME REGULATION

The use of RAIM in maritime is contemplated in the regulation since, for example, the performance standards for shipborne GPS receiver equipment claims that the GPS receiver equipment shall provide "*an indication if the position calculated is likely to be outside of the requirements of these performance standards"* [M.112/A5.1]. Very similar statements could be found for GLONASS, Galileo and BeiDou IMO performance standards.

The standard IEC 61108 specifies the minimum performance standards, methods of testing and required test results for each GNSS core constellation shipborne receiver equipment, based on their correspondent IMO Resolutions. In order to provide the indication about the reliability of positioning estimation, IEC standards indicates that a GNSS receiver shall incorporate integrity monitoring using at least fault detection algorithms, for example RAIM, or similar means to determine if accuracy is within the performance standards and provide an integrity indication. This RAIM definition does not constrain the specific RAIM algorithm implementation deliberately in order to let the manufactures implement the most suitable one for their applications. According to this IEC standard, every approved receiver shall incorporate any kind of at least fault detection algorithms, but capabilities of these algorithms may differs a lot from one manufacture to other.

The integrity indication for different position accuracy levels shall be expressed in three states:

- SAFE (green indicator): It indicates the ability of computing reliably the integrity information for the selected accuracy and the estimated performances are inside the requirements.
- CAUTION (yellow indicator): It indicates that there are not enough information con compute reliably the integrity information for the selected accuracy.
- UNSAFE (red indicator): It indicates the ability of computing reliably the integrity information for the selected accuracy and the estimated performances are outside the requirements.

It is important to remark that the concept of RAIM algorithm and also the integrity requirements differs significantly in each GNSS constellation.

- GPS standard:
    - Based in classical FD RAIM concept, requirements provided for the probability of false alarm and probability of miss detection.
    - Relaxed integrity requirements for GPS. The probability of miss detection and false alarm are of ≤ 5%. Furthermore, the probability of GPS false alarms (≤5%) is very high in order to

comply with the continuity requirements stated in IMO Recommendation A.915(22) or IMO A.1046(27), which are of 99.97%.

- Galileo standard:
    - Based in PL computation RAIM. The receiver shall provide an alarm within 10s of the starts of an event if a Horizontal Alert Limit (HAL) is exceeded for a period of at least 3s while AL and PLs concept are not contemplated for GPS
    - Integrity requirements for Galileo are much more stringent. The integrity risk shall be ≤ 10^{-5}/3h for the computed Protection Level

Because all of that it is recognised that the integrity requirements for every GNSS constellation shall be revised in order to provide a coherent and harmonised set of parameters that could be easily assessed.

In order to prove that a receiver is compliant with the requirements specified in this standard, two simple tests are proposed. The first one intends to test the performance of the receiver under safe and caution states, and the other one tests the unsafe state. Both test only check the allowed elapsed time since something causes a change in the integrity status (by a change in the number of satellites or their behaviour) until it is displayed in the integrity monitoring.

The "safe" and "caution" test reduces the number of satellites available from 8 until the integrity algorithm has not enough information to compute the estimation of the accuracy and then provides a "caution". This procedure is ambiguous because, for example, it does not indicate any minimum number of satellites.

The lack of some test parameters definition is more observable in the "unsafe" test. It claims that in nominal conditions the user shall "change the behaviour of at least 1 satellite by varying the satellite clocks with the result that the position accuracy gradually degrades until it will no longer be inside the selected accuracy level with 95% confidence level". This test is clearly deficient in terms of safety because the magnitude of the change in the satellite clock is not defined, so any user may implement RAIM algorithms that detects only too large or too small errors. The error introduced in the test should be quantified or at least limited. In addition, there are not any procedure to check if the probability of miss detection and false alarm are being correctly considered by the implemented RAIM.
Considering the simplicity of the aforementioned tests, which do not even assess the probabilities of miss-detection or false alarm, there is no assurance that the RAIM algorithm implemented in the receiver correctly provides system-level integrity. To ensure this, it would be necessary to improve the test method in order to characterize the value of the introduced error, add new tests to evaluate the complete set of requirements to the implemented integrity algorithm.

It shall be remarked that these tests only consider a single satellite failure at a time. However, some algorithms are able to detect multi-failure or even the failure of the entire constellation. They are allowed by this regulation but these capabilities are not tested and therefore it shall be not assumed that they are safe under these conditions.

2.7 COMMERCIAL SERVICES

Several companies provide high accuracy augmentation data for maritime use on a commercial basis. This information may be provided via satellite or via an internet link to the bridge equipment and is largely aimed at the high accuracy user.

Such systems may provide accuracies in the region of <10cm (PPP type service) or <2cm (RTK type service) with different usable ranges and time to convergence. It is anticipated that most services will also offer integrity but this would need to be confirmed.

The cost of commercial services could be significant both in terms of hardware and annual data subscription rates. This combined with the higher accuracies, which are likely to be more precise than many mariners require, may mean that such services are not suitable for most maritime users.

- Radiobeacon
    - Point to services offered today and potentially in the future.
    - Already in use, located along most navigable channels etc.
- SBAS
    - Some SBAS may not recognise a maritime user
    - Guidance on which SBAS to use.
    - Use at high latitudes
- RAIM
    - Standards and the need for development.
- National RTK/PPP
- Visual and Radar – use of physical AtoN
- Other ranging information – inc. R-Mode
- MSI
- What do you do with more than one augmentation source? (beacon and SBAS and between different SBAS.
- Timeline for sources.

3. FUTURE OPTIONS

- Provide guidance on the potential options for the future, recognising the choice is down to the national authority.

3.1 MAINTAIN GPS L1 CORRECTIONS

- Ability to get the equipment – encourage manufacturers to support with new hardware
- Reusing equipment from nations that have discontinued
- Introduction of SBAS 3rd party corrections / The use of EGNOS in parallel
- Availability of the technology and knowledge – transmission and reception equipment
- Concentrate only on ‘critical’ stations dependent upon the requirement to meet SOLAS obligations i.e. the degree of risk for shipping
- Cooperate with national surveying organizations

It is recognized that DGNSS beacon receivers are in wide use today and is a very reliable and well known and harmonized service world wide. Some countries has ceased transmission while others are planning to discontinue, but the number of beacons are still high. The integrity provided by the service supports safe navigation.

Today, some NSPs are facing operational and technical concerns to keep the quality of service due to aging equipment and reduced number of equipment manufacturers. It is recommended that NSPs cooperate across boundary’s to solve obsolesces or long delivery time by sharing spares.

There are basically three option for an NSP:

1) Keep service at IALA recommended service levels (ref. GL1112)
2) Continue service at a lower level given NSP. Use notice to mariners (MSI) if station is down.
3) Discontinue, see below

There are also different types of technical solutions to provide the corrections:

1) Locally produced (legacy), G1112

2) Network based, Virtual Reference Station, G1112

3) Retransmission of SBAS, G1129

Two different version for integrity monitoring: pre-broadcast and post-broadcast.

A station can be set up with a combination of the above mentioned three variants.

Two types of upgrades: full recapitalisation or partial upgrade.

Partial upgrade e.g. upgrade of transmitters only or reference equipment or IT equipment (off-the-shelf HW, e.g. PC, server, DB both central and on-site) (an example continue use legacy reference units with new IT equipment via RSIM).

3.2 PROVIDE CORRECTIONS TO MULTIPLE GNSS AND/OR GNSS FREQUENCIES

- Software based infrastructure to do it
- GNSS GLONAS available today for constellations / new frequencies in the future re. RTCM v.2.4 timeline
- Shipbourne equipment timeline / guestimate
- Software update for shipbourne equipment that is already multi-constellational – but with RTCM v.2.3
- Today the current dual frequencies are E1 and E5. In the future there may be other frequencies providing other services
- The capability to add phase corrections.

As multiple GNSS are available in the near future, maritime navigation equipment is expected to use these GNSS as well. IMO has already established performance standards (IMO Resolution MSC.401(95)) as a solution for GNSS Jamming, and has defined that multiple GNSS corrects should be able to be processed if provided. Therefore, the radiobeacon service, which is currently provided with GPS L1 correction, should be expanded to MC (Multi-Constellation) augmentation service, which should ensure integrity in the ocean as well as improved positioning accuracy for multiple GNSS. In order for the radiobeacon service to be extended to the MC augmentation service, the broadcast standards must be revised, and RTCM has completed the broadcasting standard draft (RTCM SC-104 v.2.4) for MC augmentation. Therefore, when the RTCM broadcasting standard for MC augmentation is announced, the corrections to multiple GNSS and/or GNSS frequencies shall be provided accordingly.

3.3 DISCONTINUE SERVICES

If an authority decides to discontinue Radiobeacon DGNSS services, the following issues should be taken into consideration:

- Any such decision should be based on a risk assessment of the volume of traffic and degree of risk to marine navigation within that authority’s area;
- Any such decision should incorporate an assessment of how future Position, Navigation and Timing integrity will be assured for marine traffic within that authority’s area;
- Any such decision should incorporate a consultation process with users and other stakeholders, including any neighbouring national authorities (ref. IALA Guideline G 1079);
- Any such decision should be communicated to all concerned, and only effected after timely and adequate notice has been promulgated; give guidance to authorities of a time period for notifying stakeholders i.e timely and adequate. Its recommended for authorities to remain operational until other options are fully operational, standardised and ready for ship equipage.

- The availability of other services in an authorities area of responsibility DGNSS augmentation may still be available in the waters of a country that has discontinued the service, albeit provided by a neighbouring country;
- IALA recommends maintaining the existing infrastructure for other purposes i.e. to support R-Mode, as sites and assets such as transmission antennae and frequency allocations have value and may not be easily replaced. **(timelines for discussion ??)**

4. FUTURE DEVELOPMENT

- What are the potential future systems and when are they likely to be available
- Add the future development in an annex including a timeline for the infrastructure

4.1 RANGING MODE

Studies are being conducted on the benefit of expanding the functionality of existing maritime radio systems by providing a timing signal from which the user may then calculate their position independently from GNSS. This is known as Ranging Mode (R-Mode).

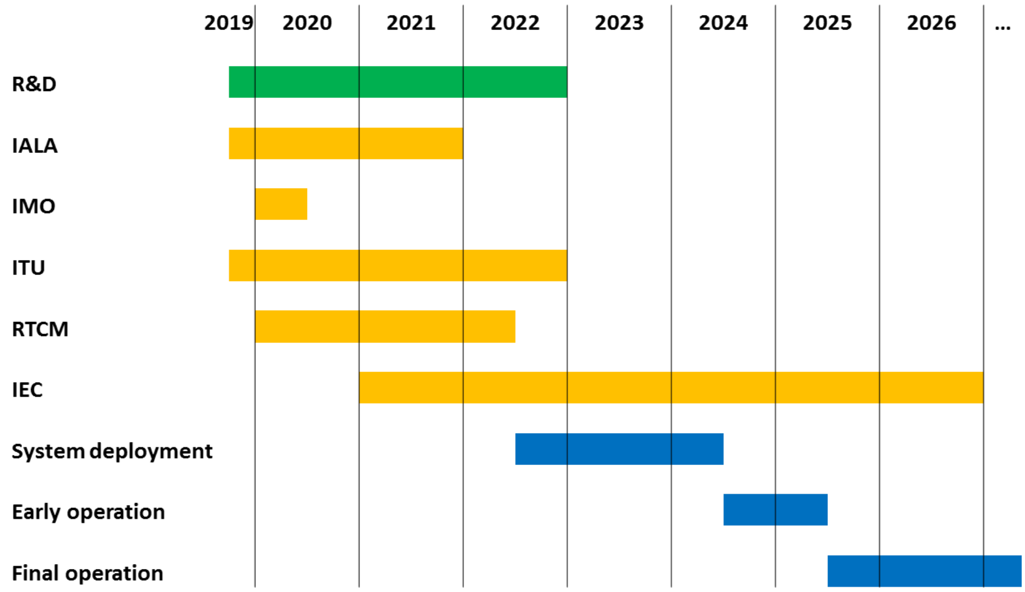
At present, the marine medium frequency (MF) radio-beacon system and the very high frequency (VHF) data exchange system (VDES) services are being considered as candidates for modification to add R-Mode functionality. By providing timing information over their normal MF or VHF transmissions, a shipboard receiver may then calculate a distance (range) to the transmitter. By calculating the range to several stations, the user is able to calculate the ship's position.

Coverage, geometry and interference issues are investigated. Several R-Mode testbeds are being established which provide MF or VHF but also MF and VHF signals. First prototypes for R-Mode transmitters and receivers are being developed.

The provision of R-Mode services requires an accurate timing source at the transmitter. This source is synchronized regularly with the R-Mode reference time which is used by all R-Mode transmitters in the area. Furthermore, a hold-over capability ensures ns accurate timing when synchronization is not possible. Depending on the classification of R-Mode as a backup or contingency the following systems or technologies can be used for synchronization of transmitters: GNSS, eLoran, R-Mode self-synchronization, fibre optics to national realization UTC or other.
Current challenges of the R-Mode implementation on marine radiobeacons are the sky-wave interference and the ambiguity resolution for the range estimation. Simulations with R-Mode signals, which make use of the entire radio beacon band, show that widening the signals would help to mitigate the sky-wave and solve the ambiguity issue.

The R-Mode system development is driven by members of the IALA. Figure . shows the IALA R-Mode roadmap.

IALA – R-Mode roadmap – Reference IALA ENG10



- GNSS evolution – changes in the GNSS constellations and services
  - Objectives of the evolution:
    - Improve performances and coverage
    - Provide additional added-value services
    - Improve resilience to GNSS vulnerabilities.
  - GNSS evolutions at different levels:
    - GNSS core constellations *reference EMRF/ERNP*
      - GPS L1 and future L2 and L5 signals
      - Galileo E1 and E5ab
      - GLONASS G1 and future G2
      - Beidou B1
    - GNSS services
      - OS Positioning
      - Medium-accuracy
      - High Accuracy
      - Search and Rescue
      - Other Services: Authentication, Timing, SAR Return Link
    - Regional Satellite Navigation Systems
      - QZSS
      - IRNSS
    - Space-Based augmentations:
      - QZSS
      - SBAS single frequency and SBAS DFMC
      - Beidou
    - GNSS user evolutions

- Hybridization
- Integrity monitoring and assurance
- High accuracy - PPP

Most part of the GNSS system are currently under evolution (different stages from the Regions). Roadmap for the evolutions:

- Galileo
- GLONASS
- Beidou

- Augmentation
- System level security issues / Cyber security
  - Identification & authentification schemes for broadcasted information → future RTCM messages should reflect
  - Network based systems should be hardened against cyber attacks
  - Tamper safe equipment → IEC 63154 standard in development (connectivity, internet, USB..)
- Communications – sending MSI for real-time integrity failures. How should this be conveyed to the user?

5. KEY POINTS TO CONSIDER

- Standards – where are we? The timeframe for modification / creation of technical standards
- L1/G1/E1 corrections as minimum requirement
  - Available as standard output of IALA Beaconsystem– Only source of Integrity for SPS-Mode receivers
  - Availability of SBAS for maritime users, partially including integrity, but same weaknesses as L1 signal itself !
  - End of life of the equipment is reached today – Upgrade options and technologies ?
    - Corrections for L2 & L5/E5
    - R-Mode compatibility
    - Guideline for DGNSS shore-based equipment upgrades is missing, reference from IALA Guideline 1060 section 2 (Need to update). Replacement options refers to R135 which is under maintenance by this document !
    - Budgets – Needed investments – Reference to GSA SC24 Project
- Multi–Constellation Receivers in use today
  - GPS & GLONASS good availability
  - GPS & GLONASS & Galileo one approved receive
- Multi-Frequency Receivers
  - IMO PS & IEC Test Standard for Galileo E1 & E5a/b
  - IMO PS for MSR (MSC.401) & Msc.1 Circ.1575 PNT Guidelines
    - Support Multi-System & Multi-Signal resilient navigation receivers.
- **ToDo**: Development of IEC/RTCM Test Standards for Wheelmark approvals

  - Ana – if the DGPS service is discontinued the equipment on vessels will still remain in place and currently there is no mechanism to force vessels/ owners to update their equipment unless there is a need through mandatory carriage requirements etc.
  - 3 different time periods
  - Regional considerations should be taken into account - Iono
- Cyber-security considerations
- Encourage Competent Authorities to develop/implement/amend a national radionavigation plan taking into consideration these guidelines.

10, rue des Gaudines – 78100 Saint Germain en Laye, France
Tel. +33 (0) 1 34 51 70 01 – Fax +33 (0) 1 34 51 82 05 – contact@iala-aism.org
www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime