e-NAV17 Input paper

Agenda item AA

Task Number ??

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Revision of IMO Res.A 915(22): a possible approach

# Summary

This paper presents a possible way forward for the revision of IMO Res. A 915(22) in the context of e\_NAV strategy and in particular the Resilient PNT multisystem receiver concept.

## Purpose of the document

The purpose of the document is to propose for discussion a possible approach for the revision of the operational requirements defined in IMO Res A 915(22).

## Related documents

Resolution A.915(22), adopted on 29 November 2001,”REVISED MARITIME POLICY AND REQUIREMENTS FOR A FUTURE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)”

# Background

This Chapter describes the rationale for the proposal to revise the Resolution IMO A.915(22).

The IMO Res. A.915(22) is dated 2001 (more than ten years ago) and the need for a revision is foreseen in the text itself.

The IMO Res A.915(22), among other actions,

* “Adopts general and operational maritime requirements for future GNSS as defined in its annex.
* Requests the Maritime safety Committee to keep this policy and requirements under review and to adopt amendments thereto, as necessary.”

Its paragraph 4.1 says “ the maritime requirements given in this annex should be continually reassessed and updated on the basis of new developments and specific proposals”.

The awareness of the need to be updated/amended is therefore clear from its adoption in November 2001 (cf paragraph 1.8 “These requirements have been limited to basic user requirements and may need to be revised” and 4.6 “ the decision making process should include means to review this resolution periodically”).

Indeed the Resolution was adopted at a time where two military controlled satellite navigation systems were available for civilian use, GPS and GLONASS (both of them, with augmentation system were recognised as WWRNS according to IMO res A.1046(27)), and future civil GNSS were at a design stage.

The Resolution was based on the recognition of the need to identify at an early stage the maritime user requirements for a future GNSS to ensure that such requirements are taken into account in the development of such a system. Further analysis, understanding and discussions in maritime fora have however shown that there is no clear consensus on all the requirements and some of the requirements are derived from the Target Level of Safety (TLS) methodology fully compliant with aviation requirements but not directly applicable to the maritime sector. As a result, no standardised solution has been identified so far for the provision of integrity at the user level and the requirements remains not applicable.

De facto,

* the resolution addresses the GNSS systems which were at a design stage in 2001 and therefore “future” at that time. It is not clear when the resolution should become applicable nor its role with reference to IMO res A.1046(27) which defines operational requirements for world wide radio navigation systems (not only GNSS) and is the current applicable one.
* Some operational requirements defined in the resolution need to be reassessed.

In line with its paragraphs 1.8, 4.1 and 4.6 it is proposed to revise the Resolution and a possible approach is presented in the following.

# Discussion

This Chapter considers a first set of issues and questions to be discussed for the revision of the Resolution and a possible approach is proposed.

## Clear objective and content

* The resolution addresses maritime user requirements for GNSS only. The questions are then: What about the other radio navigation systems? Do they need to fulfil IMO Res.A1046(27) only? Is there any difference between the requirements GNSS have to satisfy compared to the other systems? Shouldn’t the systems satisfy the same requirements?
* The resolution defines requirements for a “future” GNSS. Since no date is coupled with the concept of “future”, it is not clear when these requirements should be satisfied and the Resolution may never become applicable
  + It is proposed that the resolution addresses minimum **maritime** operational requirements independently from the system.
* In its Chapter 2, the Resolution describes the “present” situation which is related to the existing GNSS in 2001. Is this section needed?
  + It is suggested to remove chapter 2 from the resolution.

## Operational requirements

* The resolution identifies minimum maritime user requirements for general navigation and for positioning: do both have to be kept? IMO Res A 1046(22) only refers to navigation requirements.
* The phases of navigation considered are different from IMO Res A.1046(27) . IMO Res A.915(22) introduces a separate coastal phase. Which classification is the more correct one?
* Res IMO A. 915(22) breaks down positioning requirements into operations, traffic management, SAR, Hydrography, Oceanography, Marine engineering, construction, maintenance and management, aids to navigation management, port operations, casualty analysis, offshore exploration and exploitation, fisheries, recreation and leisure. These classes are further broken down. Do these classes represent all the possible ones? are there any more? i.e. is this an exhaustive list which capture all the operations?
* The Resolution introduces new operational requirements in terms of Alert limit and integrity risks. Are these needed? Are performance parameters for navigation in harbours entrances, harbours approaches and coastal waters satisfactorily defined in IMO Res A 1046(27)? Is anything else needed?
* Compared to IMO Res A.1046(27), the IMO Res.A915(22) requirements are expressed at the user level (see ANNEX A).

The properties of a “GNSS system” includes the properties of both:

* the “GNSS service” (i.e. the properties of the Signal in Space, SIS, provided by the space and the ground segment of the GNSS); and
* the user receiver.

The most critical aspect is the underlying integrity concept, which is at the user level. This requires the calculation of PLs, whose derivation cannot be independent from the “Operational Concept,” i.e. from the intended use of the navigation system in a specific operation.

Several aspects linked to a given operation need to be clarified to develop a suitable scheme for PL calculation. These include, but are not limited to:

* The consolidation of the user requirements, together with the underlying operational concept (especially in terms of operation duration, AL and IR) and operational scenario;
* The identification of possible Feared Events (FEs) which might take place during the operation (in general, the longer the operation duration, the larger the number of possible FEs which might need to be considered); and
* The characterisation of the user environment, together the definition of appropriate error models for the local sources of error (e.g. multipath or interference); and
* The identification of alternative solutions (e.g. possible integration with measurements from other sensors or other GNSS) .

All of this information was not taken into account and should be derived via theoretical studies, simulations, laboratory testing, field campaigns and coordination with stakeholders and maritime community (“end users”) representatives.

It is finally noted that, compared to aviation applications:

* The duration of a typical maritime operation is, generally, longer, so the number and the type of FEs to be considered might be different;
* Because of the different duration, the associated IR and Continuity Risk (CR) requirements might be different;
* The propagation environment around the user is completely different, especially in terms of multipath and interference;
* The user dynamics (ship, boat or vessel) is completely different from that of an aircraft.

For these reasons, the PL calculation used for aviation applications cannot be directly extended to maritime operations.

More in general IMO Res. A 915 (22) is derived from the Target Level of Safety (TLS) methodology fully compliant with aviation requirements but not directly applicable to the maritime sector.

As a result, no standardised solution has been identified so far for the provision of integrity at the user level and the requirements remains not applicable.

Some other specific remarks include:

* Continuity requirement is defined over a time interval of 3 hours. This requirement is very different to the continuity requirement defined in IMO Res. A1046(27)
  + No probability is given for requirement on accuracy: is this needed?
  + Coverage is introduced as a requirement: coverage of a system is the area where defined performance are met, it is not a requirement

It is proposed to discuss the following approach which also takes into account on going work on the resilient PNT receiver as a pillar of IMO e-NAV strategy:

* Down to Coastal Waters and Harbour Entrance/Approach, general requirements applicable to SOLAS ships should be maintained also in the post 2020 timeframe according to IMO Resolution 1046.
  + There is no evident trend for the maritime community to evolve further from this level as the minimum common required performance prescription. Should specific nautical tasks during these operational phases require additional shipborne PNT capabilities, they would not be prescribed as a general IMO Resolution different from 1046. So IMO Res A.1046 should be the reference for these phases of navigation.
* For Port operations, it becomes more and more evident that different shipborne PNT unit configurations can support different nautical tasks, with different combinations of navigation sensors and different level of required performance. This is expected to be very fragmented such that:
  1. there cannot be a general GNSS requirement defining and prescribing a minimum set of performance requirement like today defined in IMO Resolution A.915(22).
  2. it is therefore residing within the works on future guidelines for shipborne PNT unit that one can propose different levels of data type, quality and operational performance to support different functions and diverse nautical tasks and applications.
  3. Until such guidelines are not finalised, it will be not possible to assume and propose required GNSS integrity type and level of navigation performance in support of Port operations.

In particular, the current level of accuracy (1m) and the user-integrity ‘aviation’-type defined for Port operations in IMO Res A. 915(22) seem not to be justified yet, even if applied to some specific nautical tasks.

# Action requested of the Committee

The Committee WG is requested to comment the proposed way forward for the revision of the IMO Resolution A 915(22) . A first set of questions has been proposed. Next actions would include a clear definition of the objective and the content of the Resolution to be followed by a discussion on the proposed approach for the identification of maritime operational requirements down to coastal waters, for specific operations and for port navigation and operations.

### **ANNEX A: Performance parameters and underlying integrity concept**

IMO Res A.915(22) uses similar parameters as adopted for aviation applications. Specifically, six parameters are considered, i.e.:

* Accuracy;
* Integrity;
* Continuity;
* Availability;
* Coverage; and
* Fix rate.
  1. *Accuracy*

For a future GNSS system, “accuracy” is defined as “*the degree of conformance between the estimated or measured parameter of a craft at a given time and its true parameter at that time. (Parameters in this context may be position coordinates, velocity, time, angle, etc.)*”.

In general, accuracy requirements are expressed in terms of the absolute accuracy, which is also referred to as “Geodetic or Geographic accuracy.” This is defined as *“the accuracy of a position estimate with respect to the geographic or geodetic coordinates of the Earth*” .

It is finally noted that, in order to quantify the “degree of conformance” between the estimated (or measured) parameter and the corresponding true value, the 95% value of the difference, evaluated over a given period of time, is normally used.

*1.2 Integrity*

According to the resolution , “integrity” is “*the ability to provide users with warnings within a specified time when the system should not be used for navigation.*”

As mentioned, GNSS systems include both GNSS SIS and the user receiver. Therefore, the underlying integrity concept requires the user to be protected from both:

* System-related failures; and
* Possible performance degradation due to local sources of errors (e.g. multipath, interference, shadowing or other propagation phenomena).

This concept is normally referred to as “integrity at the user level.” Compared to that (“integrity at system level”) adopted for a component of the WWRNS, this concept provides an additional protection against the effects due to local sources of errors.

The need for integrity at the user level has a direct impact on the integrity monitoring process, which has the objective of determining, at each user receiver, “*whether the system performance (or individual observations) allow use for navigation purposes*”.

Specifically, “*overall GNSS system integrity is described by three parameters: the threshold value or alert limit, the time to alarm and the integrity risk. The output of integrity monitoring is that individual (erroneous) observations or the overall GNSS system cannot be used for navigation.*” In particular:

* The “Alert Limit” (or threshold value, AL) is “the maximum allowable error in the measured position, during integrity monitoring, before an alarm is triggered;”
* The “Time To Alarm” (TTA) is “the time elapsed between the occurrence of a failure in the system and its presentation on the bridge;” and, finally,
* The Integrity Risk (IR) is “the probability that a user will experience a position error larger than the threshold value without an alarm being raised within the specified time to alarm at any instant of time at any location in the coverage area.”

The concept is represented in Figure 2 for a generic Radio Navigation System which, in this case, is a future GNSS system. More in detail, integrity at the user level is ensured by calculating, at the user receiver, a maximum error bound (Protection Level, PL) for the Navigation System Error (NSE).

This estimation is done at each epoch and normally uses:

1. navigation signals (observables);
2. system integrity information; and
3. suitable models for the effects due to the local sources of errors.

It is underlined that the definition of the models mentioned at point 3 requires a detailed characterisation of the operational environment. This includes, but is not limited to, the analysis of the expected levels for multipath and interference.

Based on the input data provided at points 1), 2) and3), the resulting PL estimation takes into account both system-related failures and possible effects due to local sources of errors. In this context, it is also noted that PL calculation can be:

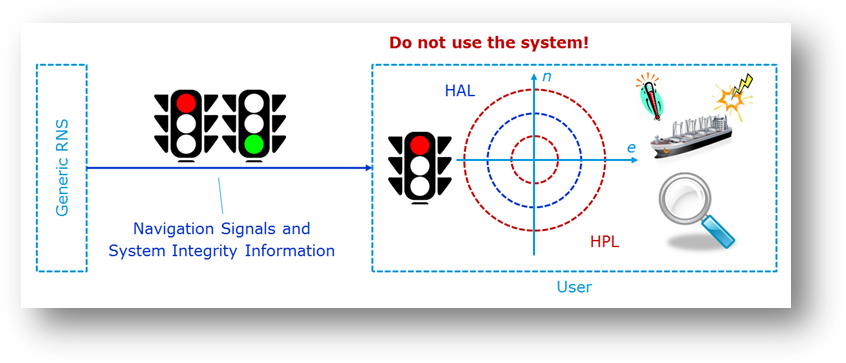
* either completely autonomous (e.g. through Receiver Autonomous Integrity Monitoring, RAIM, techniques); or
* based on additional information provided by the system (e.g. a Satellite Based Augmentation System, SBAS, for aviation application).

If the user wants to perform a given operation, the PL is compared with the AL requirement associated with that operation. If the PL exceeds the AL, the receiver will promptly warn the user that the position estimation cannot be trusted.

The PL calculation should always over-bound the actual Position Error (PE), thus avoiding critical situations where the PE exceeds the AL, while the estimated PL is below the AL (). These events are referred to as “Hazardous Misleading Information” (HMI) events and their probability of occurrence shall be below the IR requirement.



It is finally noted that the PL calculation has also a direct impact on the performance for continuity and availability..



**Figure 2:** Integrity at the user level (HPL and HAL denote the Horizontal PL and AL, respectively)

*1.3 Continuity*

“Continuity” is defined as “*the probability that, assuming a fault free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area*” [Ref 22].

The definition is based on a conditional probability, as the system is assumed to be fault free (no failure) at the beginning the operation. In this context, a failure is defined as “*the unintended termination of the ability of a system, or part of a system, to perform its required function*” [Ref 22].

It is noted that:

* The definition of continuity focuses on the actual performance experienced by a user. This is expressed in terms of both accuracy and integrity at the user level. It is therefore related to the probability of having, at the user receiver, an accurate and reliable position estimation throughout the whole duration of a given operation.
* This is conceptually different from the “service continuity” used to specify the operational requirements of a component of the WWRNS (section 3.1.1) which, in contrast, does not consider the actual user performance and is only related to the uninterrupted broadcasting of navigation signals and system integrity information within the coverage area.

*1.4 Availability*

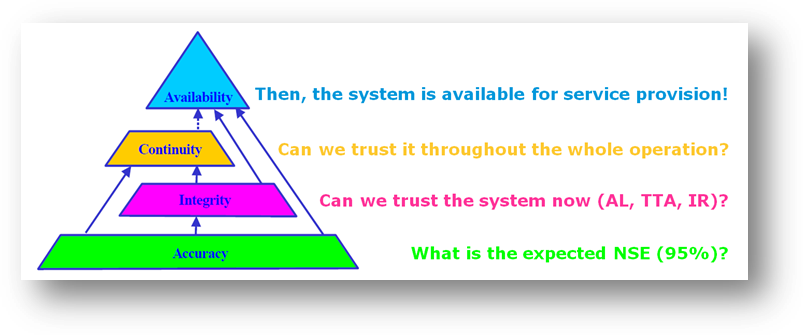
“Availability” is defined as “the percentage of time that an aid, or system of aids, is performing a required function under stated conditions. The non-availability can be caused by scheduled and/or unscheduled interruptions”.

Similar to what is done for a component of the WWRNS, two types of availability are considered for a future GNSS system. Specifically:

* “Signal availability” is “the availability of a radio signal in a specified coverage area”
* “System availability” is “the availability of a system to a user, including signal availability and the performance of the user’s receiver”

In this context, it is noted that:

* The definition of signal availability exactly matches that used for a component of the WWRNS);
* The definition of system availability is, in contrast, significantly different. In particular:
* As a GNSS system includes the properties of both the GNSS service (SIS) and the user receiver, the system availability for a future GNSS system focuses on the actual availability of the system to a user for navigation purposes. As a consequence, it must consider the signal availability and the actual performance at the user receiver. Before starting a given operation, this performance shall include:
  + - Accuracy;
    - Integrity (at the user level); and
    - Continuity (throughout the whole operation).
* On the contrary, system availability for a component of the WWRNS does not consider the actual performance at the user level. As mentioned, it is only related to the capability of the system of providing reliable navigation signals in the coverage area.
* This difference originates from the two different integrity concepts, “integrity at system level” and “integrity at the user level,” used for a component of the WWRNS and for a future GNSS system, respectively. Because of this difference:
  + Signal availability is used as performance parameter to define the operational requirements of a component of the WWRNS; while
  + System availability, including signal availability and the performance at the user receiver, (i.e. as defined in), is used as parameter to define the requirements of a future GNSS system.
* As system availability for a future GNSS system includes the user receiver performance in terms of accuracy, integrity (at the user level) and continuity, the four requirements are actually related and can be represented using a “pyramid,” which is normally referred to as “Required Navigation Performance, RNP, pyramid.”
* The pyramid, which is reported in Figure 3, represents the decision-making process which is performed by a user before starting a given operation. In summary: if the system is accurate and reliable at the beginning of the operation; and if the system can be trusted throughout the whole operation, then the system is available to perform that operation and can be actually used.



**Figure 3:** RNP Pyramid

The RNP pyramid highlights that a key element in the decision-making process is the assessment of the integrity at the user level, i.e. the decision, at the user receiver, whether the system can be trusted or not.

As discussed above, this decision is based on the PL estimation and on the subsequent comparison with the AL requirement associated with the operation to be performed. As a consequence, the more conservative the PL estimation, the larger the possible performance degradation in terms of continuity and availability. For that reason, it is essential not to overestimate the PL while, at the same time, being compliant with the IR requirement.

*1.5 Coverage*

“Coverage” is defined as “*that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of performance*”

Again, this definition highlights the importance of the expected performance at the user level.

*1.6 Fix Rate*

The fix rate is defined as “*the number of fixes per unit time*,” where a fix is defined as “*a position determined by processing information from a number of navigation observations*” .

It is noted that the fix rate might be an important aspect when post-processing techniques are used to further improve the accuracy provided by a RNS. A typical example is Kalman filtering, where subsequent “snapshot” fixes are used in conjunction with a model which properly estimates the user dynamics.

These requirements are detailed in Appendix 2 and 3, respectively, of the IMO A.915(22) resolution . The following table taken from indicates the maritime user requirements for general navigation. It has to be noted that this resolution introduces level of performance more stringent than IMO Res A.1046(27), in particular for accuracy where 1m is required for navigation in port and the integrity requirements are given at user level.

