ENAV17-10.5.6

Service Description: Multi Source Positioning Service

Issue: 1

Issue Status: Approved

Issue Date: 18/05/2015

Lead Author	Reviewer	Approved for Release
Name: Dr. Paul Williams	**Name:** Transnational Project Co-ordination Group	**Name:** Project Steering Committee
Job Title: Principal Development Engineer	**Job Title:** N/A	**Job Title:** N/A
Partner: GLA	**Partner:** All	**Partner:** All
Signature: pp Alwyn I. Williams	**Signature: pp Alwyn I. Williams**	**Signature: pp Alwyn I. Williams**

Executive Summary

GNSS (principally GPS and GLONASS) have become the primary source of positioning, navigation and timing (PNT) for maritime operations. GNSS-based positioning is used by many systems on vessels and it is the source of the vessel's position used by AIS and GMDSS. Safe navigation, the protection of the marine environment and the efficiency of access to ports in the North Sea Region are highly dependent on the availability, continuity accuracy and integrity of GNSS- based positioning.

GNSS is vulnerable to jamming and natural interference. When GNSS is denied, PNT information can be seriously affected in ways that increase risks to the safety of navigation. PNT data may become unavailable for a period, resulting in alarms being raised by many bridge systems. In some cases, Hazardously Misleading Information (HMI) may occur in which position errors are large enough to have an impact on navigation safety but small enough that no alarms are raised. These erroneous positions could go unnoticed by the mariner and significantly increase the risk of grounding or collision.

Additionally, the functioning of The Maritime Cloud, the backbone of e-Navigation data communications, will depend on reliable vessel positioning information for its geo-location based architecture.

The resilient PNT solutions within ACCSEAS aim to provide dependable positioning at all times, even under GNSS interference and jamming conditions, through the use of complementary backup positioning systems that are independent of GNSS. The Multi Source Positioning Service (MSPS) is a critical service that assures the appropriate use of positioning and its associated uncertainties for the portrayal and reporting of the vessel's position and for applications within other services on board and ashore.

This document presents the background to and development of the ACCSEAS Multi-Source Positioning Service (MSPS). It demonstrates the links to the overarching IMO e-Navigation architecture, outlines the infrastructure provided for the MSPS, the required input technical services and output operational services. It also considers standardisation and the future evolution of the service.

Contents

Document Disclaimer

Document is uncontrolled when removed from iManage (either electronic or printed)

Document Information

Client	ACCSEAS Project
Project Title	ACCSEAS
Work Package No.	5
Document Title	Service Description: Multi Source Positioning Service
Description	This document describes the results of the efforts in developing and testing the Multi-Source Position Service (MSPS).
Date	18/05/2015
Lead Author	Dr. Paul Williams
Lead Author's Contact Information	GLA R&RNAV, Trinity House, The Quay, Harwich, Essex CO12 3JW Direct: +44 (0) 1255 245146 Mobile: +44 (0) 7739 191253 E-mail: paul.williams@gla-rrnav.org
Contributing Author(s)	Dr. Alan Grant, Mr. Chris Hargreaves
iManage Location	29924
Circulation	1. Project Files (i-manage) 2. Transnational Project Co-ordination Group 3. Project Steering Committee
NSRP Secretariat Approval	Yes / No

1 Introduction

1.1 Rationale

GNSS (principally GPS and GLONASS) have become the primary source of positioning, navigation and timing (PNT) for maritime operations. GNSS-based positioning is used by many systems on vessels and it is the source of the vessel's position used by AIS and GMDSS. Safe navigation, the protection of the marine environment and the efficiency of access to ports in the North Sea Region are highly dependent on the availability, continuity accuracy and integrity of GNSS- based positioning.

GNSS is vulnerable to jamming and natural interference. When GNSS is denied, PNT information can be seriously affected in ways that increase risks to the safety of navigation. PNT data may become unavailable for a period, resulting in alarms being raised by many bridge systems. In some cases, Hazardously Misleading Information (HMI) may occur in which position errors are large enough to have an impact on navigation safety but small enough that no alarms are raised. These erroneous positions could go unnoticed by the mariner and significantly increase the risk of grounding or collision.

Additionally, the functioning of The Maritime Cloud, the backbone of e-Navigation data communications, will depend on reliable vessel positioning information for its geo-location based architecture.

The resilient PNT solutions within ACCSEAS aim to provide dependable positioning at all times, even under GNSS interference and jamming conditions, through the use of complementary backup positioning systems that are independent of GNSS. The Multi Source Positioning Service (MSPS) is a critical service that assures the appropriate use of positioning and its associated uncertainties for the portrayal and reporting of the vessel's position and for applications within other services on board and ashore.

1.2 Role

The Multi Source Positioning Service (MSPS) provides position, navigation and timing information with a dependable level of performance wherever it is needed within the ACCSEAS test-bed. The specified service level will assure the accuracy, integrity, availability and continuity of service of the PNT information and will indicate the bounds of uncertainty associated with the estimated accuracy of the PNT solution. This will enable the robust and confident portrayal of position for mariners and shore based operators. It will also ensure that the navigation risks inherent in e-Navigation services are reduced through the recognition of the quality of PNT data and the use of dependable uncertainty and integrity information. Examples of services that could benefit are the display of safety margins to prevent groundings and collisions and the use of uncertainties in calculations of intended routes and route exchange.

1.3 Pre-requisites

The ACCSEAS Multi-Source Positioning Service assumes that shore-side infrastructure is available for the provision of Resilient PNT; including signals in space, propagation data, associated reference station installations, and transmitter and reference station almanac information.

The service follows the principles of the IMO overarching architecture for e-navigation. The MSPS Operational Services will be provided for the ACCSEAS E-Navigation Prototype Display (EPD).

2 The Structure of The Multi-Source Positioning Service

2.1 Relationship to IMO e-navigation Architecture and MSP

This section describes the IMO e-navigation architectural context within which the Multi Source Positioning Service resides and is based on [1]. Further detail is provided in the ACCSEAS Work Package 4 – Architecture Report [4].

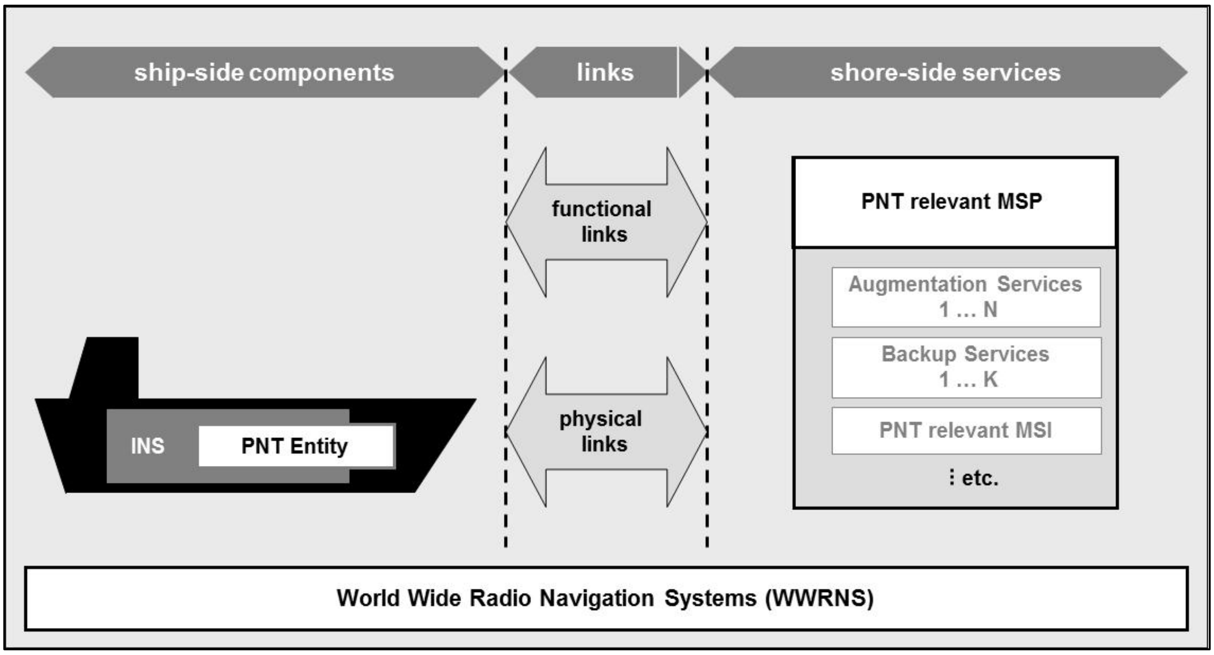


Figure 2.1 - Generic architecture of the maritime Integrated PNT system. *After [1].*

Figure 2.1 shows the general architecture of the maritime Integrated PNT System. The system is based on GNSS as the primary positioning source with shore- and ship- side components and communications links. Integrated use ensures the accurate and reliable provision of ships' PNT data to applications (and other e-navigation services) during all phases of voyage in a timely, complete and unambiguous manner [1]. The ACCSEAS Multi-Source Positioning Service follows this generic architecture.

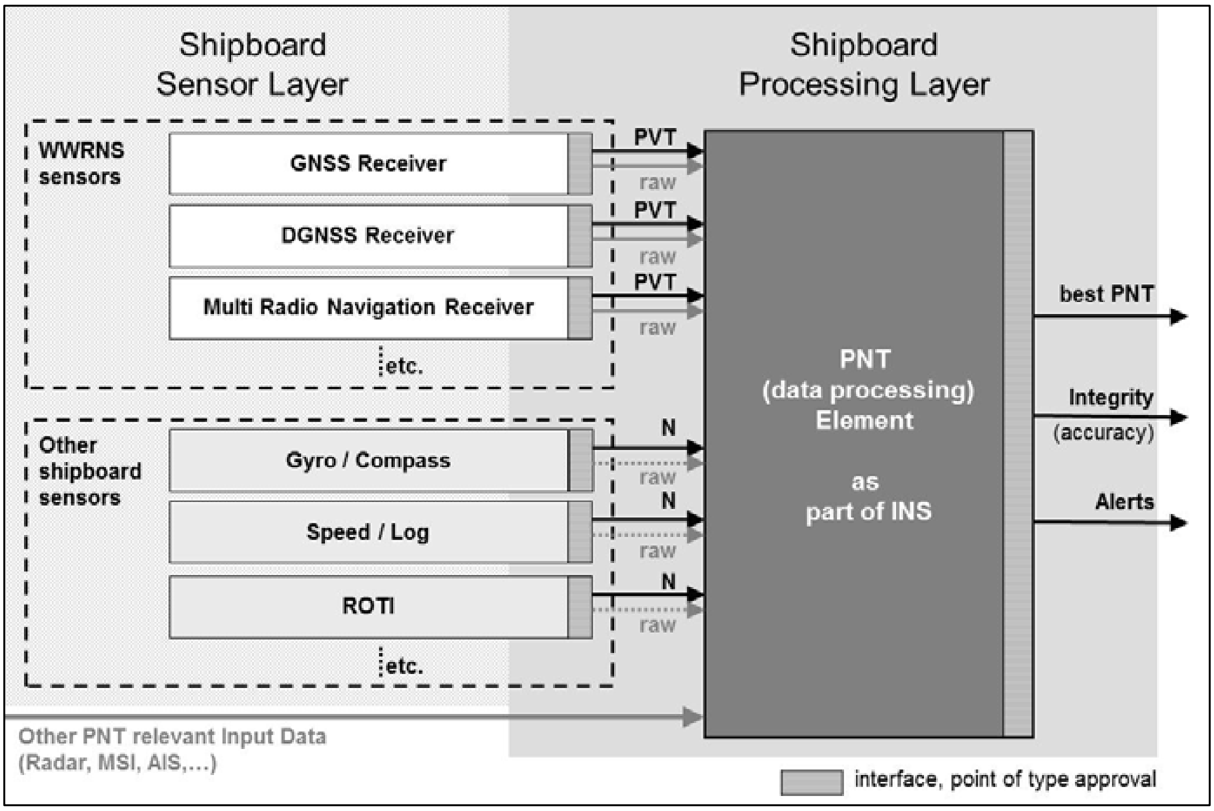


Figure 2.2 – Ship-side PNT entity with PNT Data Processing Element.

Referring to Figure 2.2, document [1] states:

"The PNT Element is an approach to meet identified user needs such as improvement and indication of data and system integrity. The presented approach enables the use of variety of PNT relevant sensors and sources. Their combined use exploits the redundancy by processing data on raw data level. The utilization of PNT relevant augmentation coming from different shore-side services (MSP), the integration of additional PNT relevant data sources (e.g. ePelorus, Racon), and the application of future PNT relevant MSI (Maritime Safety Information) is supported by this approach. By implementation of integrity monitoring functionalities the PNT Element has the potential to identify and provide the best PNT data and to indicate the current accuracy and integrity. Integrity information provided by the PNT Element is the basis for automatic reporting and improved alert management dealing with PNT."

The ACCSEAS implementation of the Multi-Source Positioning Service will follow this architecture for the most part, limiting the prototype service's scope to radionavigation systems; Figure 2.3.

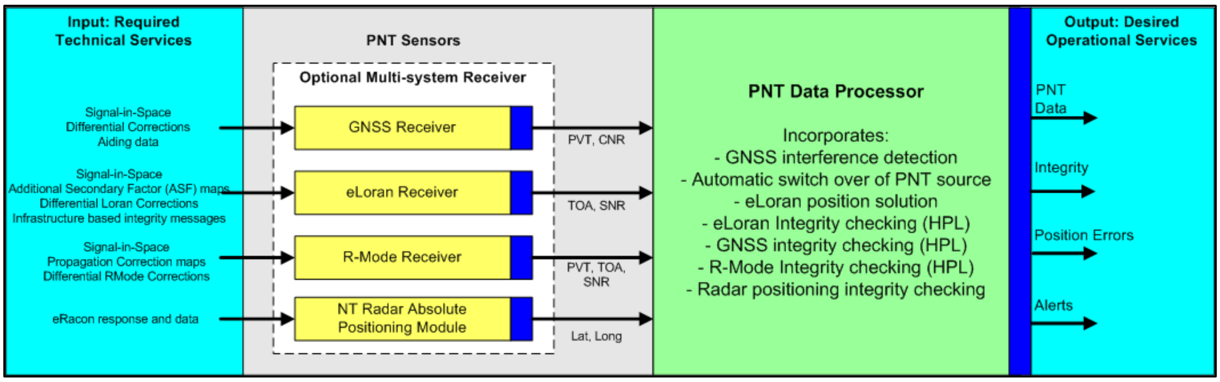


Figure 2.3 – Structure of the ACCSEAS ship-side Multi Source Positioning Service architecture.

Figure 2.3 expands horizontally on the architecture of Figure 2.2 by illustrating the requirement for input Technical Services to support the separate services supplying the "PNT Sensors" within the Multi-System Receiver.

2.2 Entity Diagram of the Multi-Source Positioning Service

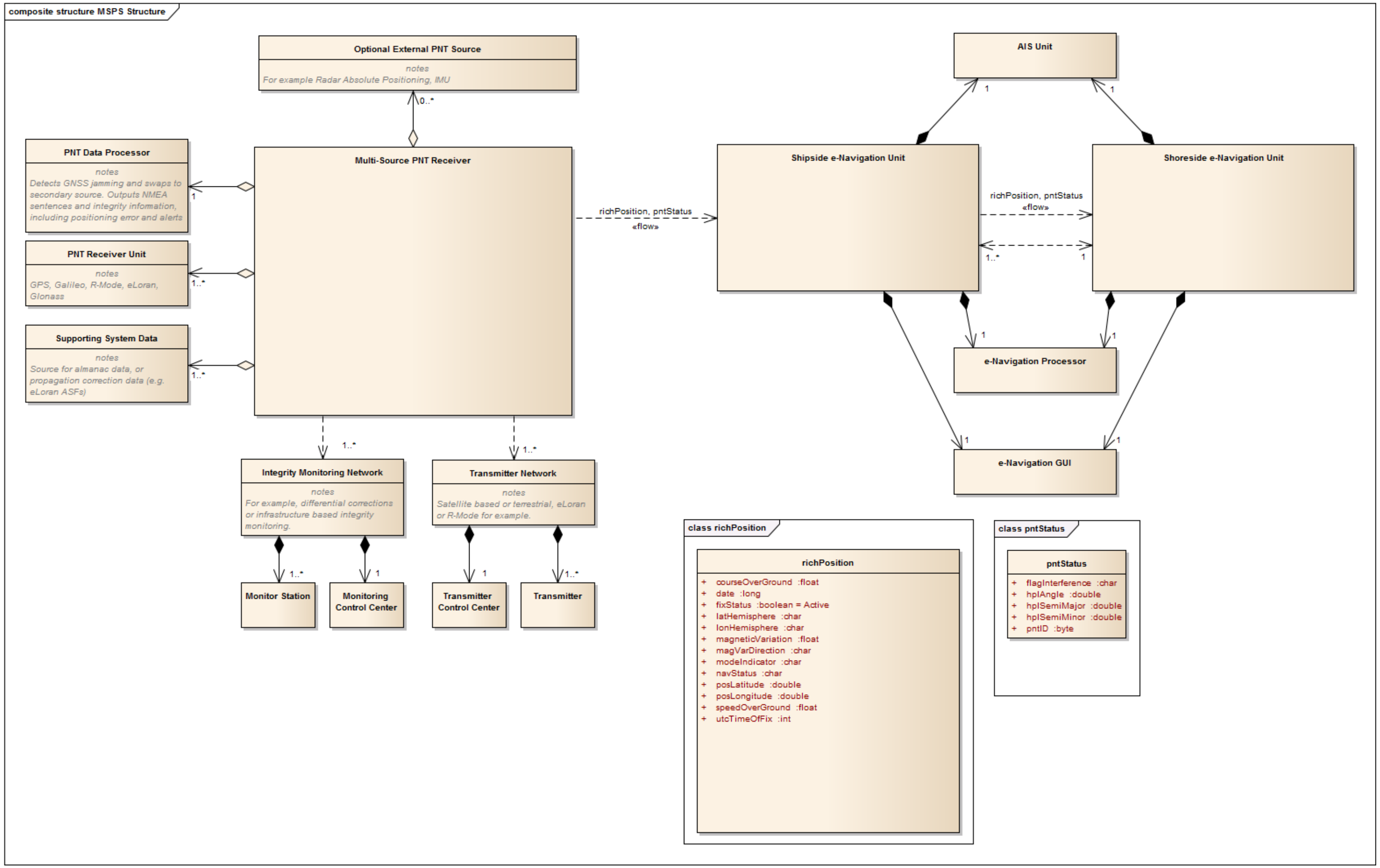


Figure 2.4 – Entity Diagram for Multi-Source Positioning Service. ***This does not yet consider IHO S-100 data models but is a reference for future development work in this area.***

Figure 2.4 presents an entity relationship diagram, which identifies the main entities within the Multi-Source Positioning Service. No attempt is made to be compatible with S-100 product descriptions at this stage, but the diagram attempts to be self-explanatory and serves as a starting point for further discussion on the construction of the service and the service's system requirements.

2.3 Required Input Technical Services

Required input Technical Services are outlined in this section.

2.3.1 RNP Service Levels

Required Navigation Performance service levels differ for each voyage phase, and may differ for each supported e-Navigation service. For example, the IMO has stipulated a 10m (95%) **Accuracy** requirement for Port Approach, Coastal and Ocean phase navigation for future GNSS, as shown in Figure 2.5. There are also requirements for **Integrity**, **Availability** and **Continuity**.

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[2] (seconds)
	Horizontal (metres)	Alert limit (metres)	Time to alarm[2] (seconds)	Integrity risk (per 3 hours)				
Ocean	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Figure 2.5 – Extract from IMO Resolution A915 on requirements for future GNSS.

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours[3]	Coverage	Fix interval (seconds)
	Horizontal (metres)	Alert limit (metres)	Time to Alarm[2] (seconds)	Integrity Risk (per 3 hours)				
Ocean	1000	2500	60	10^{-4}	99	N/A[2]	Global	60
Coastal	100	250	30	10^{-4}	99	N/A[2]	Regional	15
Port approach and restricted waters	10	25	10	10^{-4}	99	99.97	Regional	2
Port	1	2.5	10	10^{-4}	99	99.97	Local	1
Inland Waterways	10	25	10	10^{-4}	99	99.97	Regional	2

Figure 2.6 – IALA suggested maritime minimum requirements for general navigation employing "backup" systems.

In addition, IALA has suggested minimum requirements for "backup" navigation systems; Figure 2.6.

With the advent of the Route Topology Model (RTM) it is possible to associated the RNP parameters shown in figures Figure 2.5 and Figure 2.6 with each leg, node and junction of an RTM instance. Each e-Navigation service may also have a set of RNP requirements and each will need to be made aware of the MSPS' capabilities with respect to these requirements.

In certain locations, and under some conditions, the backup source of PNT may demonstrate less capability than the requirements due to infrastructure constraints; the MSPS service should alert the mariner and shore based support in these situations.

2.3.2 Spectrum of Services

Taking into account the considerations of Section 2.3.1, the MSPS may also use knowledge of the spectrum of services (service catalogue) offered at the vessel's current location in the RTM – such that a Horizontal Alert Limit (HAL) appropriate to each service can be assigned for subsequent comparison with the current Horizontal Protection Level (HPL).

2.3.3 Navigational Charting Uncertainty

Current methods of assessing charting uncertainty include S-57 attributes POSACC, SOUACC and TECSOU, which provide bathymetry positioning accuracy and depth sounding accuracy. This data may be considered within the MSPS through an additional input component to the HPL computation.

2.3.4 Differential Positioning Correction Data

Differential-Loran data will be transmitted over the Loran Data Channel (LDC), currently Eurofix in Europe.

Differential-GPS data will be transmitted over the network of IALA radiobeacons, or EGNOS when deemed appropriate.

Differential-R-Mode correction data may be required for Medium Frequency R-Mode.

2.3.5 Propagation Data – eLoran and R-Mode

eLoran Additional Secondary Factor (ASF) data is typically measured once and for all, fixed and published by storing it within the flash memory of a receiver. Such data can be made available through manual download from a website and uploaded to the receiver.

However, in the e-Navigation environment, propagation data can be associated with legs and nodes of the RTM. Conveniently, up-to-date data can then be made available through automatic download via the Maritime Cloud, at the appropriate time, as a vessel enters a particular leg of its route.

Data will need to be made available in XML format for transfer, and be defined in the IHO S-100 Registry.

Similar propagation data may well be required for Medium Frequency R-Mode. There is no intention to implement such a scheme under the ACCSEAS project, but it may be considered to be a future e-Navigation service.

2.3.6 Almanac Data

New transmitters, monitor sites and differential reference stations may appear from time to time and data updates would be required for the MSPS to take these into account.

Again, up-to-date data can be made available through automatic download via the Maritime Cloud, at the appropriate time, as a vessel enters a particular leg of its route.

Data will need to be made available in XML format for transfer, and be defined in the IHO S-100 Registry.

2.3.7 Integrity Information

System status information will be vital to maintaining knowledge of integrity and positioning accuracy. eLoran integrity alerts shall be generated by an infrastructure (external) based integrity monitoring system, mostly to mitigate and alert the user to rare “early skywave” events[1]. Early Skywave is an effect whereupon a copy of the “wanted” groundwave signal pulse arrives by skywave reflection when the ionosphere is particularly low in altitude owing to strong solar activity. The magnitude of the effect depends on the distance between a user and the respective eLoran transmitter, and the user’s geomagnetic latitude.

On the rare occasions when strong sky wave interference is likely, or there is likely to be a transmitter or differential correction data outage, users should be notified within a particular time-to-alarm period (see Figure 2.5 and Figure 2.6).

Currently, eLoran integrity information is disseminated by the Loran Data Channel (LDC), however the Maritime Cloud may also provide the data link.

Similar integrity information should be provided for R-Mode once the technology is deemed mature enough for use within e-Navigation.

2.4 Required Output Operational Services

For ACCSEAS, the MSPS will be required to output data to other services, these data have been outlined in Section 4, and summarised in Table 2.

[1] The term “Early Skywave” refers to the earlier than normal arrival, at a user’s receiver, of a copy of the wanted signal via skywave such that the skywave version of the signal interferes with the standard tracking point of the wanted signal.

3 Functional Description and Design

3.1 Top Down Design

Figure 3.1 shows a high level top-down design diagram of the ACCSEAS MSPS.

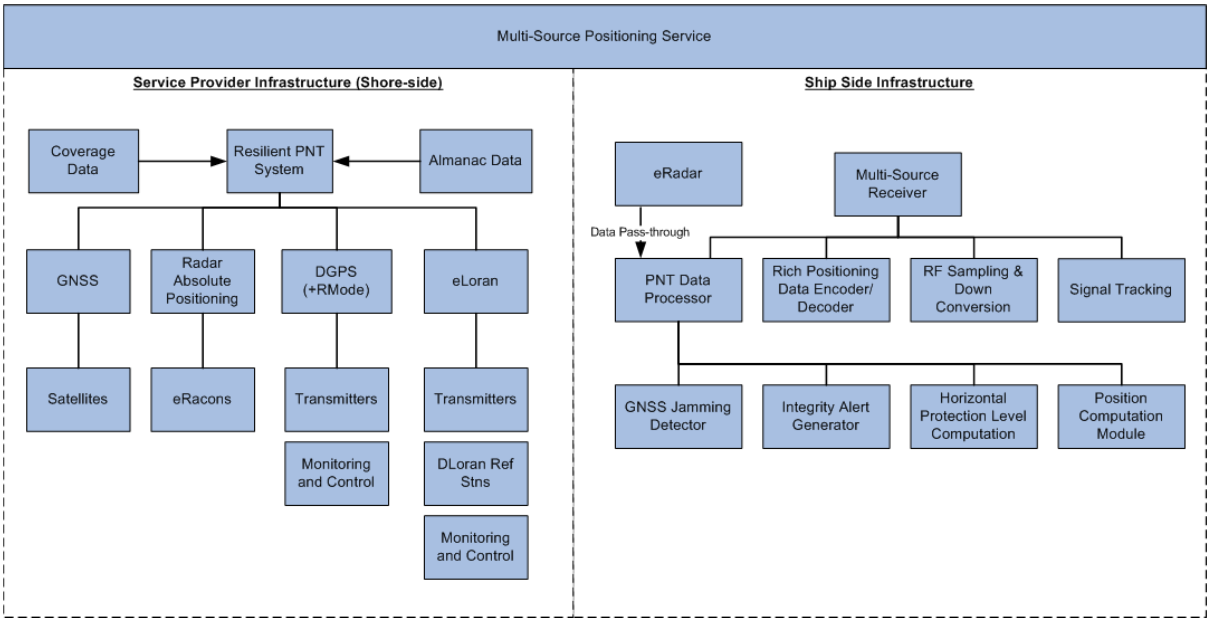


Figure 3.1 – Top down design of Multi-Source Positioning Service. (Note that radar absolute positioning, although demonstrated, will not be implemented within the timeframe of ACCSEAS).

The next sections consider the shore side and ship side infrastructure of the ACCSEAS Multi-Source Positioning Service.

3.2 ACCSEAS Shore Side Components

Shore-side components include the fixed infrastructure and equipment to provide Technical Services for the Multi-Source Positioning Service.

3.2.1 ACCSEAS Resilient PNT System

The ACCSEAS Resilient PNT System consists of components of GPS, eLoran, and MF R-Mode. Figure 3.2, also shows the Functional and Physical data communications links between the shore-side and ship-side components.

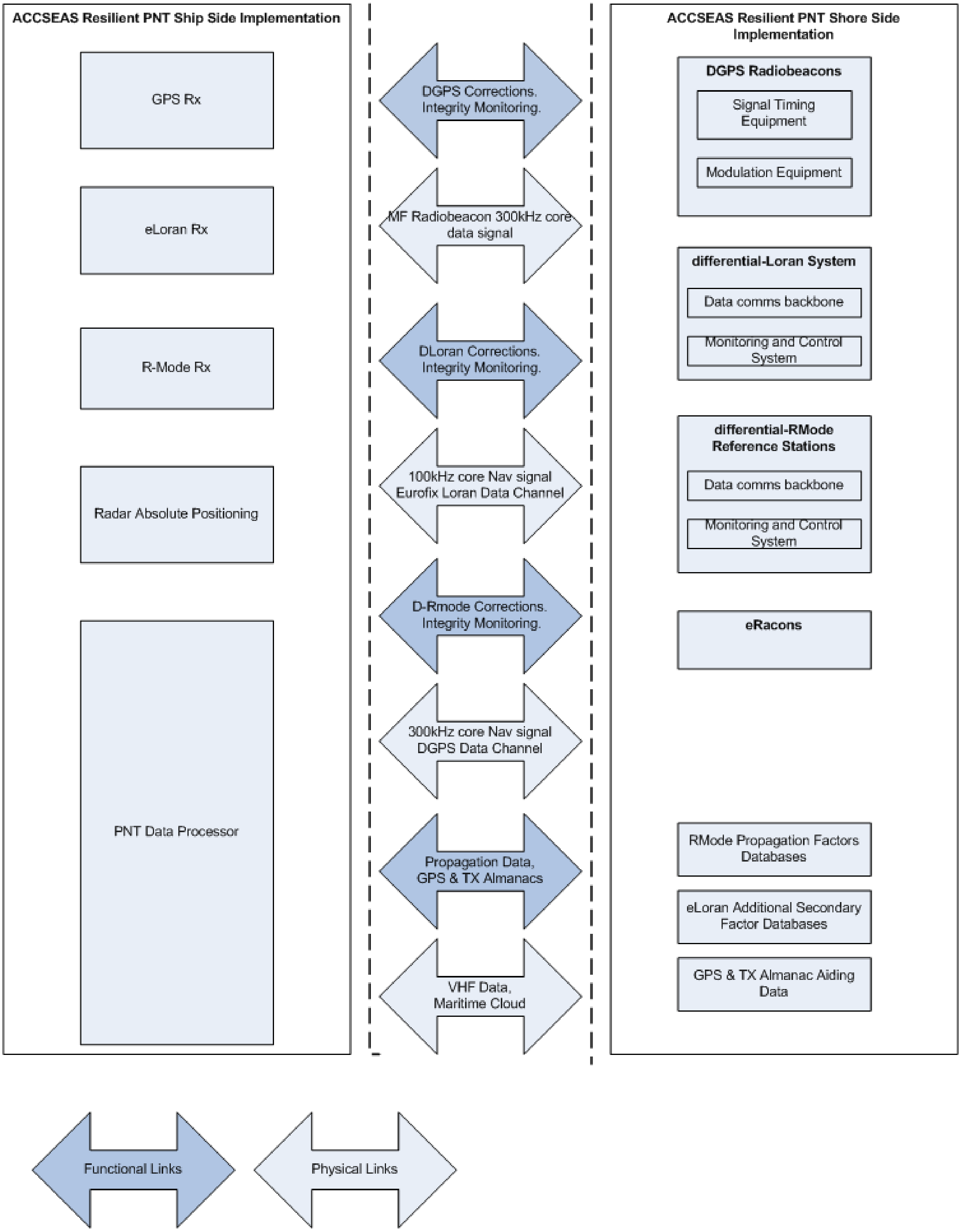


Figure 3.2 – Organisation of ship-side and shore-side components of the Resilient PNT system with Functional and Physical Data Links.

3.2.1.1 MF Radiobeacon R-Mode and VHF AIS

The IALA DGPS radiobeacon network broadcasts differential-GPS correction data using Minimum Shift Keying between 285kHz and 315kHz (Medium Frequency). Correction data is generally receivable by ship board DGPS receivers out to 200 Nautical Miles from each beacon.

Under ACCSEAS it is planned to add a suitable tracking signal to the basic DGPS broadcast of the beacon at Ijmuiden in The Netherlands. The data collected from this trial installation will be used to inform on the potential performance capability of a full-blown navigation and positioning system based on R-Mode technology.

In addition, AIS, transmitted on part of the marine VHF radio band, provides a convenient source of radio signals distributed about the coasts of the NSR and inland waterways. Adding a ranging component to the AIS broadcast could provide a useful source of positioning.

A feasibility study on all of these aspects has been performed under the ACCSEAS project [2].

3.2.1.2 eLoran – Differential-Loran Reference Stations

eLoran is supported in the ACCSEAS test-bed through the provision of differential-Loran Reference Stations in The Humber Estuary, and Hoek Van Holland (covering the Port of Rotterdam). eLoran positioning accuracy along the port approaches within these areas meets the IMO 10m (95%) accuracy requirement. Differential-Loran reference stations are also in place at Harwich/Felixstowe, Medway on the Thames Estuary, Dover, Middlesbrough, the Humber Estuary, Leith (Forth of Firth) and Aberdeen

3.2.1.3 Radar Absolute Positioning - eRacons

So far two independent technologies that could potentially provide a radar absolute positioning service have been identified. A trial of one of these systems was performed by the ACCSEAS project, for which a report is available [3].

3.3 ACCSEAS Ship Side Components

Ship-side components include the equipment and software to provide Operational Services for the Multi-Source Positioning Service.

3.3.1 Multi-Source Receiver (MSRX)

A diagram of the ACCSEAS Multi-Source Receiver is shown on the right hand side of Figure 3.1. The MSRX contains separate eLoran and DGPS receivers, and the ability to read in NMEA sentences containing radar absolute positioning data for analysis within the built-in PNT Data Processor. MF R-Mode functionality may be added in the future by changing the firmware of either the DGPS receiver or the eLoran receiver.

3.3.2 eRadar

One option is to replace the existing ship's radar with a prototype "New Technology Radar" that is capable of triggering eRacons and receiving the returned eRacon signature. The eRadar then demodulates the eRacon position data, which is modulated onto the dash of the eRacon return. The eRadar then performs a position computation using either one or two such eRacon returns. Each eRacon provides a single line-of-position (LOP) consisting of range and bearing information from the eRadar to the eRacon. Positioning may be performed using one LOP, but two LOPs are required for the highest level of accuracy.

Another option is to employ a “passive” radar technique, which relies on image pattern recognition techniques through the addition of an interface box to the already existing ship’s radar. Absolute radar positioning will not be implemented in the ACCSEAS timeframe.

3.3.3 PNT Data Processor

The Resilient PNT Data Processor Module performs several functions, and is the key innovation in the implementation of the MSPS. The functions include the following:

- Computes a position solution based on TOA measurements from eLoran or RMode receivers, as required
- Stores and applies propagation data corrections (e.g. eLoran ASFs)
- Applies differential correction data to the pseudorange measurements of terrestrial PNT services
- Computes and maintains the Horizontal Protection Levels (HPL) for complementary PNT services and the primary GPS service
- Detects incidents of GPS interference and jamming, and monitors the interference level
- Potentially can be used to analyse the data output from an eRadar for the integrity assurance of absolute radar positioning
- Automatically and seamlessly switches the main PNT output of the service to the best available backup source given the prevailing interference/jamming conditions
- Generates alarms for the purposes of notifying the mariner and shore-based stakeholders

Figure 3.3 shows this functionality in diagrammatic form.

Some or all of the above functionality will likely be commuted into the functionality of future receivers. This is unlikely to occur under ACCSEAS, but the ACCSEAS Resilient PNT Data Processor Module provides a platform that is independent of receiver developments. In addition, the module’s functionality and algorithmic implementations may be used to inform required receiver algorithm design.

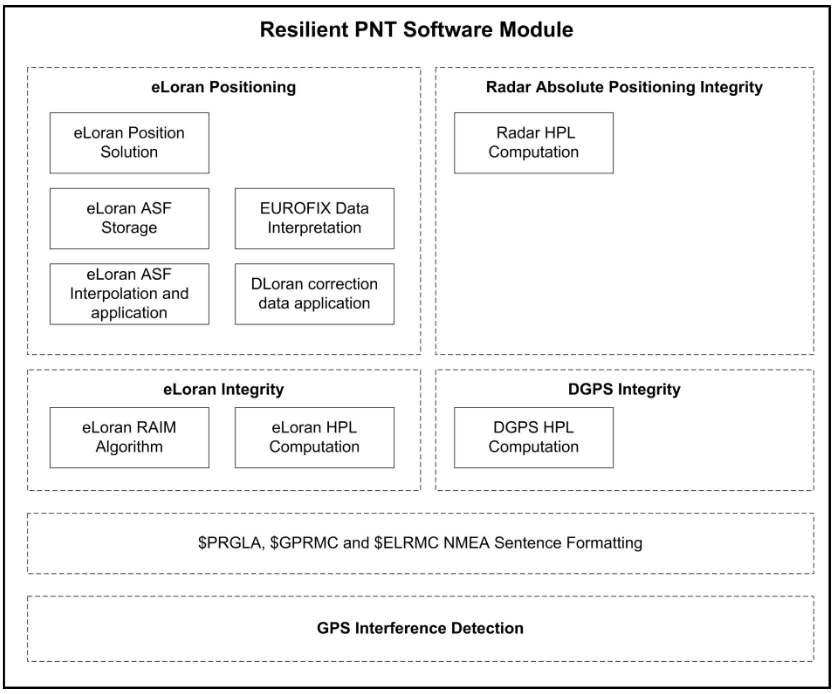


Figure 3.3 – The main functions of the ACCSEAS Resilient PNT Data Processor. (Note that the HPL computation for radar will not be implemented under ACCSEAS.)

3.3.4 Rich Positioning Data Encoder/Decoder

All interfacing to the outside world is performed through a data stream. Output data will be provided via NMEA sentences similar to those described in Table 1.

Sentence Header	Content
$GPGGA	Global Positioning System Fix Data
$GPGLL	Geographic position, latitude / longitude
$GPGSA	GPS DOP and active satellites
$GPGSV	GPS Satellites in view
$GPHDT	Heading, True
$GPRMB	Recommended minimum navigation info
$GPRMC[2]	Recommended minimum specific GPS data
$GPVBW	Dual Ground / Water Speed
$GPVTG	Track made good and ground speed

[2] This will be modified by the Resilient PNT software for output.

$GPXTE	Cross track error, Measured
$GPZDA	Date & Time
$GPMSS[3]	Marine beacon differential-GPS data
$PRPNT	Resilient PNT specific data containing HPL and integrity alerts. This is a proprietary sentence.

Table 1 – Proposed output NMEA sentences.

The ACCSEAS EPD has been designed to accept three types of sentence from the Multi-Source Receiver; $GPRMC, $ELRMC and $PRPNT; examples and data field descriptions follow:

$GPRMC,095802,A,5154.9347,N,00125.7874,E,014.0,206.8,010313,0,E*61

095802 = Time of day, 09:58:02

A = Validity flag, A-ok or set to 'V' for InValid

5154.9347 = Latitude 51 degrees 54.9347 Minutes

N = Latitude North

00125.7874 = 1 Degree 25.7874 minutes Longitude

E = Longitude East

014.0 = Speed 14kts

206.8 = Heading 206.8 degrees True

010313 = Date March 1st 2013

0 = Magnetic Variation (not used)

E/W = Magnetic Variation (not used)

*61 = Bit-xor checksum

eLoran navigation data is indicated with the non-standard talker ID EL:

$ELRMC,095755,A,5154.9566,N,00125.8246,E,006.8,210.5,010313,0,E*72

In addition, integrity alerts and PNT source indication is provided to the EPD as follows:

$PRPNT,1.0,1,A,008.5,005.3,003.1,116*2A

1.0 = Sentence version number (may be subject to change pending software development)

1 = PNT Source to use (1 = GPS 'GPRMC', 2 = eLoran 'ELRMC', 3 = Radar 'RDRMC' etc… 0 = do-not-use flag)

[3] Or equivalent.

A = GPS Jamming Flag A-ok; J=Jamming; S=Spoofing (future addition)

008.5 = HPL in meters (8.5m), if this breaches the HAL, will set the validity flag to 'V' for corresponding navigation 'RMC' sentence.

005.3 = Error-ellipse major axis (5.3m), for eLoran this is equal to the HAL

003.1 = Error-ellipse minor axis (3.1m)

116 = Angle of ellipse major-axis from True North.

*2A = usual bit-xor checksum

3.3.5 RF Sampling, Down Conversion and Signal Tracking

These elements are not considered further here, but are deemed the responsibility of the manufacturer of the Multi-Source Positioning Receiver.

3.4 IHO S-100 Product Specifications

S-100 Product Specifications will be required to be developed for data provided by Technical Services and the Operational Services provided by the Multi-Source Positioning Service. The first step will be the development of data models for the following:

1. Vessel positioning information
2. eLoran ASF data
3. eLoran transmitter almanac data
4. R-Mode transmitter almanac data
5. Differential-Loran Reference Station almanac data

A Task Group has been established under the IALA e-Nav committee, with the group being invited to consider the following:

- The most suitable means of defining the format of the data. This may be the use of an S-100 product description, or another suitable means.
- Develop a database suitable to contain the IALA DGNSS station list.
- Develop a database, or databases, suitable to contain the necessary eLoran reference station almanac and ASF data.

3.4.1 Vessel Rich Positioning Information Data Model

The aim of this data model is to describe the data required to be provided concerning vessel positioning to other ships and shore users, such as VTS. Section 4 describes the data that should be included in this data model.

3.4.2 eLoran ASF Data Model

eLoran ASF data is typically characterised as sets of gridded data. One grid is provided for each eLoran transmitter. ASF data may be divided into two forms depending on phase of voyage.

Coastal Phase ASFs are large grids covering the entire coastal region of a nation or administration. They may be based on radio frequency propagation modelling, calibrated using sparse sets of measurement data. These grids are typically not associated with any single differential-Loran reference station, and would provide lower accuracy positioning should a primary source of PNT suffer an outage.

Port Approach Phase ASFs are associated with one or more differential-Loran reference stations, and have local coverage of approximately 50km radius from the reference station. Port Approach phase ASFs are typically produced by making precise measurements, and provide 10m (95%) accuracy performance.

Both types of ASF grid are candidates for distribution over The Maritime Cloud. A vessel new to a region could automatically download, via the Maritime Cloud, ASF data for the target port approach, or coastal region.

Data would include:

- Designated name of grid
- Gridded ASF values
- Applicable coverage area
- Applicable transmitter
- Associate DLoran reference station(s) name(s) and ID(s)
- Date of issue
- Version number
- Gridded error data for inclusion within integrity equations (RAIM)
- Expected ECD in the area to aid receiver tracking
- Identification of the service provider

3.4.3 eLoran Transmitter Almanac Data Model

eLoran transmitters are characterised by their wide geographical separation, each providing regional signal coverage of approximately 1000km radius.

Almanac data would be suitable for distribution over The Maritime Cloud. A vessel new to a region could automatically download transmitter almanacs for the region and configure eLoran software receiver. New transmitters could be included in the almanac and updates issued. IALA already maintain a list of Loran transmitters in their document *“IALA List of Radionavigation Services – Loran-C and Chayka 1996”*, and new list will be needed that includes eLoran transmitters.

Data would include:

- Geographical Location in WGS-84 co-ordinates
- ECD – Envelope to Cycle Difference
- Power
- Station identification
- Operational status
- Emission Delay (ED)

3.4.4 Medium Frequency (MF) R-Mode Transmitter Almanac Data Model

MF R-Mode transmissions are broadcast on the IALA radiobeacon differential-GPS service (285kHz to 315kHz). Each transmission provides regional signal coverage of approximately 200km service radius.

Almanac data would be suitable for distribution over The Maritime Cloud. A vessel new to a region could automatically download transmitter almanacs for the region and configure the R-Mode software receiver. New transmitters could be included in the almanac and updates issued. IALA could maintain this transmitter list.

Data would include:

- Geographical Location in WGS-84 co-ordinates
- Power
- Station identification
- Operational status

3.4.5 AIS (VHF) R-Mode Transmitter Almanac Data Model

AIS R-Mode would be enabled by a tracking receiver locking onto the bit transitions of the data modulation on the GMSK AIS broadcasts at 161.075 MHz and 162.025 MHz.

AIS based R-Mode almanac information would include the ID and locations of AIS base stations in the region.

3.4.6 Differential-Loran (DLoran) Reference Station Almanac Data

Differential-Loran Reference Stations are not so widely geographically distributed as eLoran transmitters, rather in a region of eLoran coverage there are many more reference stations than transmitters. A DLoran Reference Station is typically associated with a particular Port Approach. These are **NOT** radio stations, but monitors that are connected to the Internet, and which communicate with eLoran transmitters, which then broadcast the differential corrections to the mariner using the Loran Data Channel (LDC). They have local coverage of approximately 50 km radius. Almanacs would be suitable for distribution via The Maritime Cloud, and are candidates for IALA to maintain a list. A vessel new to a region could automatically download, from the Maritime Cloud, Dloran Reference Station almanacs for the region and configure the eLoran software receiver.

Data would include:

- Geographical location of the reference station in WGS-84 co-ordinates
- Reference station ID
- The nominal ASF for each eLoran transmitter served by the reference station
- Applicable eLoran transmitters
- Data update interval
- Status and integrity alerts
- The identification of the local service provider

3.4.7 Other Considerations

Propagation data, and differential services, may also be required for R-Mode service provision. Similar arguments, and specifications, to the differential-Loran service can be applied here. Although not covered here, radar absolute positioning services may also require almanacs of shore side transponders or passive reflectors.

3.5 Portrayal

The clear and unambiguous portrayal of a vessel’s location is a vital consideration for the integrity of information provided to the mariner. Plotting the vessel’s position as a single point on an ECDIS is misleading, with the mariner assuming that his/her positioning source, be it

GNSS, eLoran or R-Mode, is perfect. In reality every source of PNT contains measurement errors. Contributions from measurement errors include the variance of pseudorange measurements, HDOP, propagation data errors, differential correction data, ionospheric effects, data representation and charting errors all contribute to a vessel's positioning uncertainty. All of these error sources may be summed and transformed into positioning errors in latitude and longitude; the precision of the service. Figure 3.4 shows positioning error over time for GPS as measured from a static location.

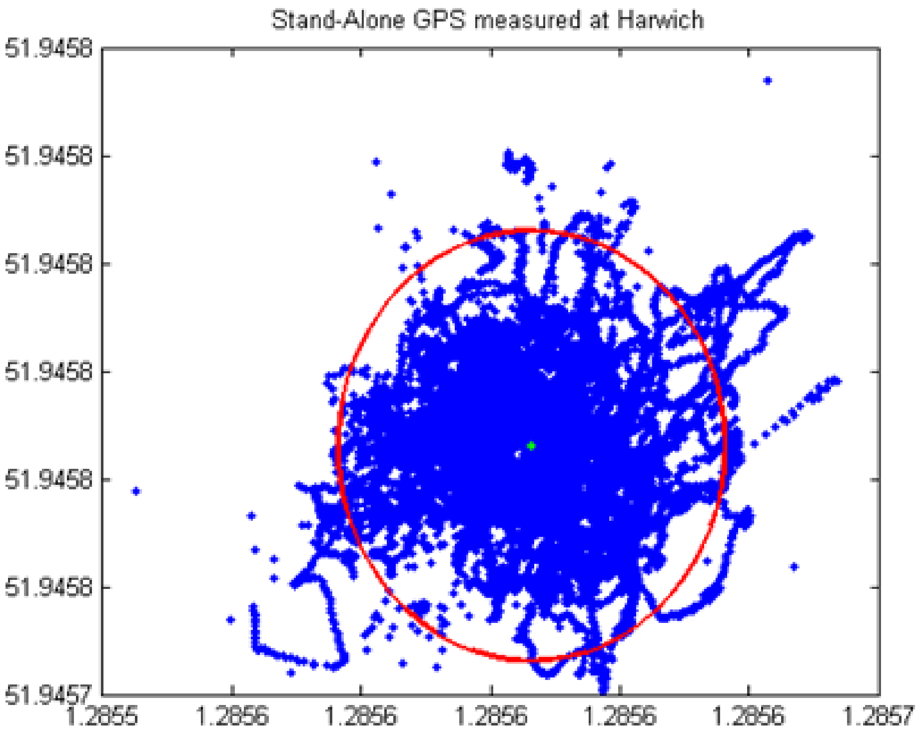


Figure 3.4 – GPS positioning error.

Portrayal of a vessel's position and position errors should be considered from the language of the appropriate standards organisation documentation, including IHO S-52 document performance standard for ECDIS, IEC Specifications (IEC 62376, IEC 62288), and IMO A.817 – performance standards for ECDIS.

3.5.1 Horizontal Alert Limit (HAL) and Horizontal Protection Level (HPL)

All errors contributing to the system error are expressed as uncertainties. These uncertainties are summed in quadrature and transformed into the positioning domain. The resulting two-dimensional position error may be represented as an error ellipse. The error ellipse is linearly scaled to a positioning probability level corresponding to the desired integrity risk level (see Figure 2.5 and Figure 2.6). Traditionally the HPL is a computation performed by system designers to ensure the proper functioning of the system, but the same computation may be made available aboard ship in order to offer the mariner some reassurance that his PNT system is performing within the bounds recommended for particular applications (requirements).

For integrity purposes, the MSPS ship-side component will calculate a HPL, for any navigation system, given knowledge and assumptions of the uncertainties.

It then becomes possible to plot the HPL ellipse at a convenient location on the ECDIS in addition to a finite point on the chart representing the vessel.

Associated with each voyage phase (and indeed e-Navigation service) is a Horizontal Alert Limit, which is the limit (in metres) of positioning error tolerable by the given e-Navigation service or voyage phase. Should the HPL breach the HAL an alarm should be generated and the Multi-Source Receiver can then switch sources of PNT to one that is demonstrating an HPL that is lower than the HAL.

Figure 3.5 illustrates the concept of the Horizontal Protection Level and the Horizontal Alert Limit, by overlaying these ellipses on the vessel's position on a chart, or on a separate panel of the display. The size, shape and orientation of the HPL ellipse (green) is dependent on the currently predicted error bounds to positioning accuracy; and is built up from an error budget that is dependent on the PNT system currently in use by the vessel. As such, the HPL computation takes into account such parameters as noise on the pseudorange measurements, geometry to satellites or transmitters (Horizontal Dilution Of Precision), errors in augmentation data (ASF, differential corrections etc.), and the current integrity risk of the current e-Navigation service or application; for example Port Approach requires 10^{-5} integrity risk over 3 hours.

It should also be possible to add in the effects of errors in the nautical charts and other sources, thus portraying all error sources in one computation, providing a single display element and minimising screen clutter. Figure 3.5 represents normal operation with a vessel travelling with an arbitrary direction and speed.

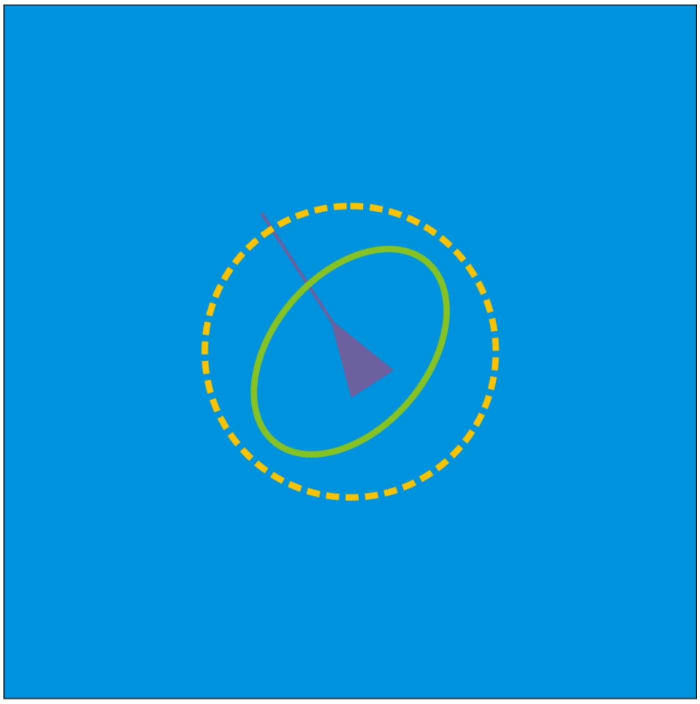


Figure 3.5 – Horizontal Protection Level (green ellipse) and Horizontal Alert Limit (yellow dashed circle), represented by ellipses around the vessel indicator (purple). This configuration indicates positioning is good and can be relied upon; HPL<HAL.

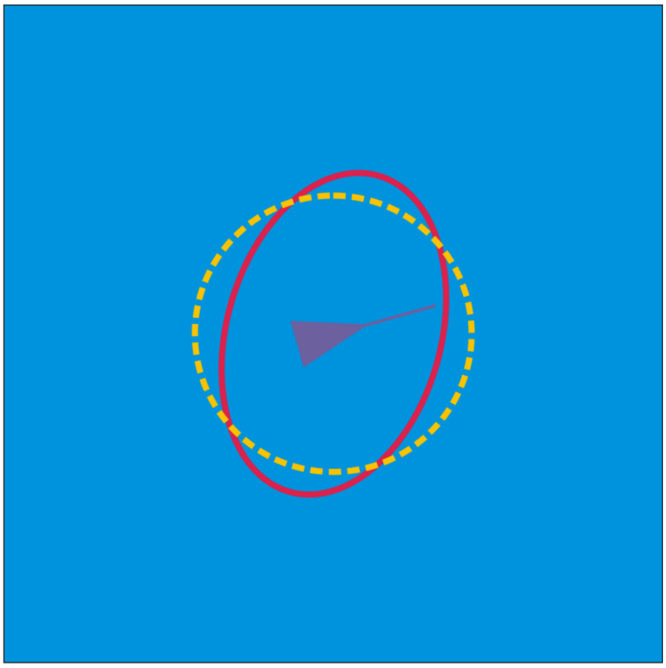


Figure 3.6 – Horizontal Protection Level (red ellipse) has breached the Horizontal Alert Limit (yellow dashed circle). This configuration indicates positioning accuracy performance is predicted to be bad and cannot be relied upon; HPL>HAL.

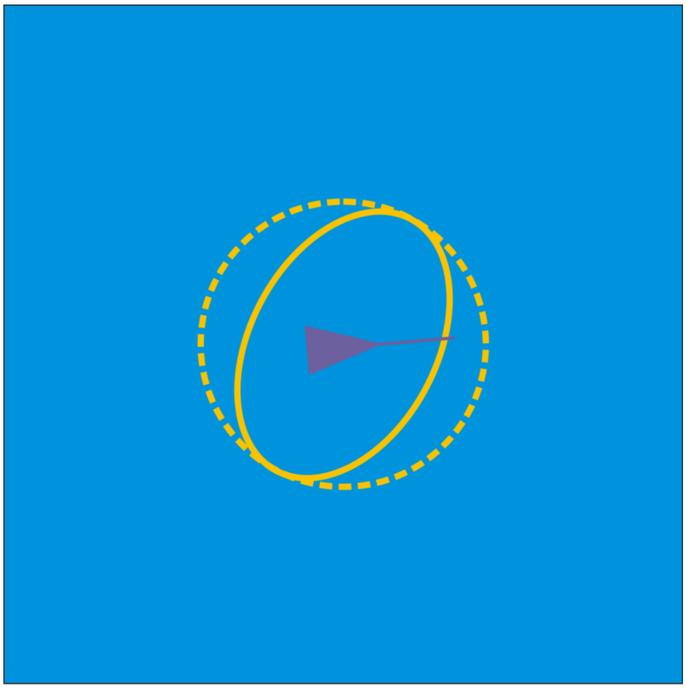


Figure 3.7 – Horizontal Protection Level (yellow ellipse) has reached the level of the Horizontal Alert Limit (yellow dashed circle). This configuration indicates estimated positioning accuracy performance is becoming poor but is still at the HAL level; HPL=HAL.

Figure 3.6 and Figure 3.7 indicate the situation where positioning accuracy performance is poor and borderline respectively. Each of these situations could be indicated by an audible alarm sounding on the bridge. The borderline case could cause alarms to appear and disappear quickly depending on the exact situation, so some level of hysteresis or observation threshold should be built into the system to avoid the annoyance of the reactivation of cancelled alarms.

Note that the contribution of the PNT source's positioning error to the vessel's cross-track error depends on the orientation of the vessel with respect to the calculated HPL ellipse.

Overlaying the HPL and HLA on a vessel plotted on a chart in this way has one obvious problem; the observability of the HPL will depend on the particular zoom level of the chart employed at the time. However the usefulness of the HPL representation increases as the mariner zooms into a chart and requires more detail. The usefulness of this overlaid approach should be assessed by consultation with mariners.

An alternative option, and one that is preferred for ACCSEAS, is to display the HPL ellipse on a side panel of the chart, with an overlay of a scaled wireframe diagram of the vessel with bow pointing to the top of the display. This has been implemented in the e-Navigation Prototype Display (EPD) as developed by the DMA; Figure 3.8.

The error ellipse is rotated depending on ship's heading so that the mariner has an indication of cross track and along track contributions of the PNT source's position error. This may be useful to provide the mariner with confidence during the navigation of narrow channels and coastal regions, particularly in situations where the primary source of PNT (typically GNSS) is not being used and the terrestrial fall back is subject to geometrical effects due to a limited number of transmitters.

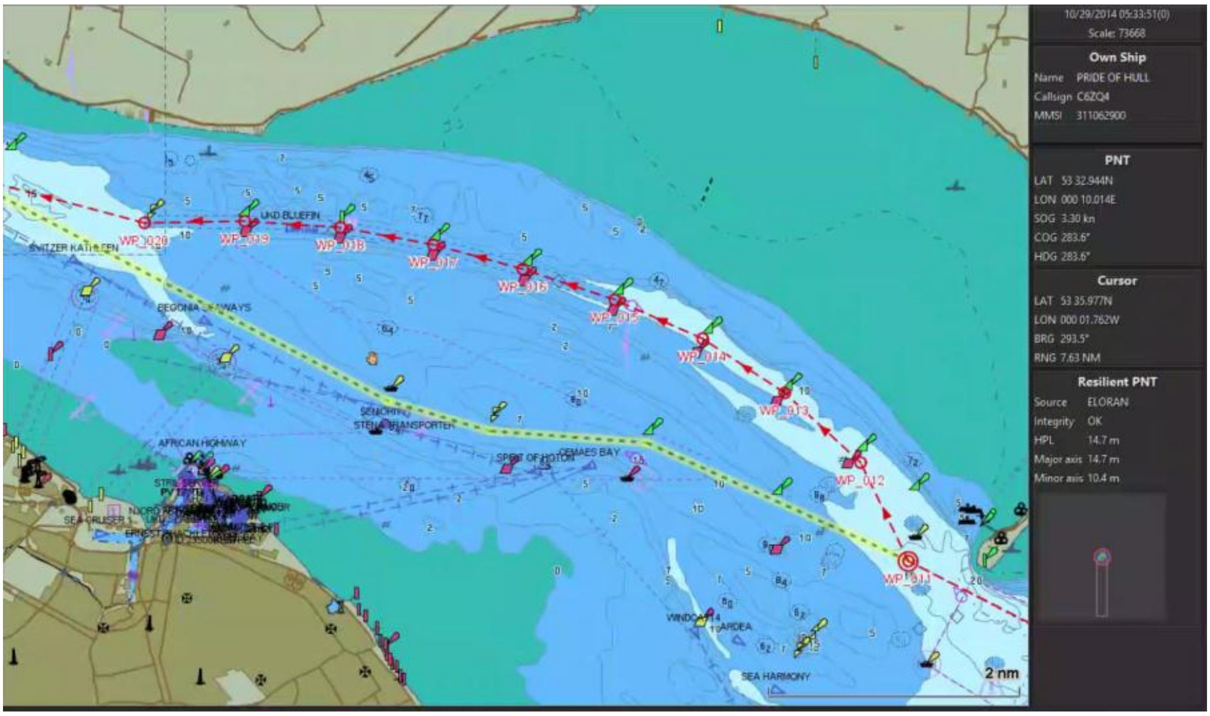


Figure 3.8 – EPD showing Resilient PNT display panel in the lower right.

The HPL value may also be provided as a variable, computed in the background, for other operating e-navigation services and can be combined with the known location of chart elements to provide more accurate and timely information regarding proximity to charted structures, and other vessels.

Note that the use of an HPL is akin to a simplified volumetric navigation system such as that proposed by the ARIADNA project.

In addition, the HPL may be broadcast to VTS operators either by AIS, or via the Maritime Cloud. This would provide shore-side monitoring and alerts on the quality of a vessel's positioning fix. Viewing the HPLs from multiple vessels could provide an indication to shore-side about whether problems with GPS are localised to a particular vessel, or are system wide problems. Information concerning system-wide or regional interference problems may then be disseminated using the MSI e-Navigation service.

3.5.2 Other Methods of Portrayal

Other methods of portrayal of position, PNT source and position error are described in IEC 62288 – 2013 – 02; Figure 3.9 and Figure 3.10.

The ship's true scaled outline may be displayed with the outline expanded, in a different colour, according to an estimate of the cross track and along track position error computed from a scaled version of the Horizontal Protection Level. A plotted position may include the time of the position fix, and the source of the positioning information.

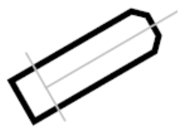
1.1 a	**Own ship – true scaled outline** The user may select to present own ship as a true scaled outline oriented in the direction of heading relative to CCRP and drawn using a thick solid line style with the same basic colour used for own ship symbols. Automatic selection of the true scaled outline is permitted (see 5.1.1). The true scaled outline shall not be used when heading is unknown in a gyro/THD-stabilised mode, or when the beam of the outline is less than 3 mm. NOTE A loss of heading will force the radar into head-up mode (see IEC 62388); in this case, the true scaled outline is still permitted.	

Figure 3.9 – Portrayal of true scaled outline of vessel. Outline may be expanded by cross track and along track error derived from the HPL ellipse.

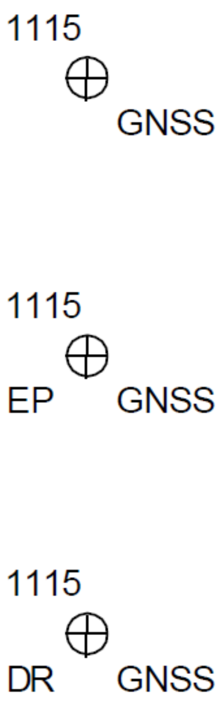
3.2	**Plotted position** A plotted position (Fix, EP, and DR) shall be presented as a circle with crossed lines centred at the position. The circle shall be 5 mm in diameter. The length of the crossed lines shall be the diameter of the circle. The circle and crossed lines shall be drawn using a thin solid line style. The position shall be labelled with time and an indication of its source for example GNSS, L (Loran), R (Radar range), V (Visual bearing), VR (Visual bearing and Radar range) . If the position is an estimated position, it shall also be labelled with the letters “EP”. If the position is a dead reckoned position, it shall also be labelled with the letters “DR”. Alphanumeric text used to label the position shall be the same basic colour as the symbol.	

Figure 3.10 – Portrayal of ship’s position. Information on time of fix and source of fix may be displayed.

4 Multi-Source Positioning Service Attributes for ACCSEAS

Annex A describes a set of proposed attributes to be input, computed, or maintained by the MSPS. Table 2 shows the subset of those attributes that shall be implemented within the ACCSEAS test-bed. These will provide the rich positioning information necessary for the ACCSEAS e-Navigation services to accomplish their positioning tasks in a resilient manner, and for the main purpose of demonstrating the MSPS.

Attribute	Value Range	Source of information and/or NMEA[4]	Portrayal
Expected Accuracy (MSPS_1)	1m to 1km	Estimated PNT System capability through coverage prediction. Route Topology Model	Estimated 95% circle around vessel. Static value associated with vessel location or current element of Route Topology Model within which vessel resides.
Position (MSPS_6)	Latitude: ±90° Longitude: ±180° Degrees and decimal degrees	Multi-Source Receiver $GPRMC $ELRMC	Numeric data and charted graphical position shown in accordance with IEC 62288. See Section 3.5.2.
Horizontal Protection Level (HPL) (MSPS_7)	0 to 2.5km Resolution:0.1m	Multi-Source Receiver $PRPNT	Portrayed on screen as a scaling of own ship outline.

[4] Where applicable.

			OR, portrayed on screen as a separate panel with scaled wireframe of vessel overlaid. Used internally for checking against alarm conditions. See Section 3.5.2.
PNT Source Indicator (MSPS_8)	Set of binary digits encoded to represent sources available. ON / OFF Flag	Multi-Source Receiver $PRPNT	Textual description on ECDIS as described in IEC 62288. See Section 3.5.2.
GNSS Interference Detected (MSPS_10)	ON / OFF Flag	Multi-Source Receiver $PRPNT	Onscreen and audible alarm.
Course Over Ground (MSPS_11)	Decimal degrees from WGS84 North Resolution: 0.1°	Multi-Source Receiver $GPRMC $ELRMC	Textual information. Minute line superimposed on vessel position indicator(MSPS_6)
Speed Over Ground (MSPS_12)	Knots Resolution: 0.1kt	Multi-Source Receiver $GPRMC $ELRMC	Textual information. Length of minute line superimposed on vessel triangle mark (MSPS_11)

Cross Track Error (MSPS_14)	0 to 2500m Resolution: 0.1m	E-Navigation Prototype Display Computed from HPL $PRPNT	Textual information. Computed from HPL in EPD software
Horizontal Alert Limit of Service (MSPS_19)	Metres 0 to 2500m Resolution: 1m	Determined from published IMO requirements depending on particular voyage phase or intended maneuver. Also influenced by intended ACCSEAS e-Navigation services.	Textual information as required. Circle drawn on display key. Maintained as a variable within.
Vessel Positioning Reference Point (MSPS_30)	N/A	Measured and fixed parameter	Internal parameters of PNT data processor module.
Radio-navigation antenna Lever Arm(s) (MSPS_32)	Array of lever-arm values from vessel positioning reference point, in X and Y co-ordinates (metres). Positive X coordinate in a direction forward of origin. Positive Y coordinate in a direction starboard of origin.	Measured and fixed parameter	Internal parameters of PNT data processor module.

Table 2 – Attributes to be implemented under ACCSEAS.

5 Test Methodology

Tests should focus on demonstrating that the PNT system is resilient by showing that it continues to provide a positioning output under a total loss, a minor degradation and a severe degradation of the primary source (GPS/GNSS).

The resilience of other e-navigation services that are dependent upon MSPS should be demonstrated where possible.

The MSPS test and evaluation may be partitioned between practical real-life demonstrations of scenarios and simulation scenarios that support the evaluation of human factors including the investigation of scenarios with multiple vessels.

IALA publishes guidelines on test-beds, and these should be followed.

5.1 Multi-Source Positioning Service (MSPS)

The MSPS is demonstrated/tested through three different means, the MSPS receiver itself, the use of MSPS data within the EPD and also simulated GPS jamming data. Each approach is considered separately.

5.1.1 MSPS Receiver

The MSPS receiver has been developed for the project and consists of a DGPS receiver module, an eLoran receiver module and a computer module, along with the necessary power supply unit (Figure 5.1).

The aim is for each receiver module to operate independently and for their respective outputs to be provided to the computer module where the ACCSEAS resilient PNT algorithms will process and analyse them and identify the “best” solution to be output to the mariner.

In order to test the performance and also to enable the test vessel to quickly return to its normal configuration, each receiver module output is also provided directly to a port on the outer case of the unit.

The computer will use a Windows™ operating system and will also host software to control the various receiver modules. The ACCSEAS algorithms will be provided by the project partners on receipt of the unit and will be tested independently.

This is the first time that a maritime multi-source receiver has been developed and produced for use aboard vessels. As such there are no test standards for such a mode of operation within IEC. ACCSEAS has an opportunity to influence and recommend an approach to the testing of this new type of receiver.

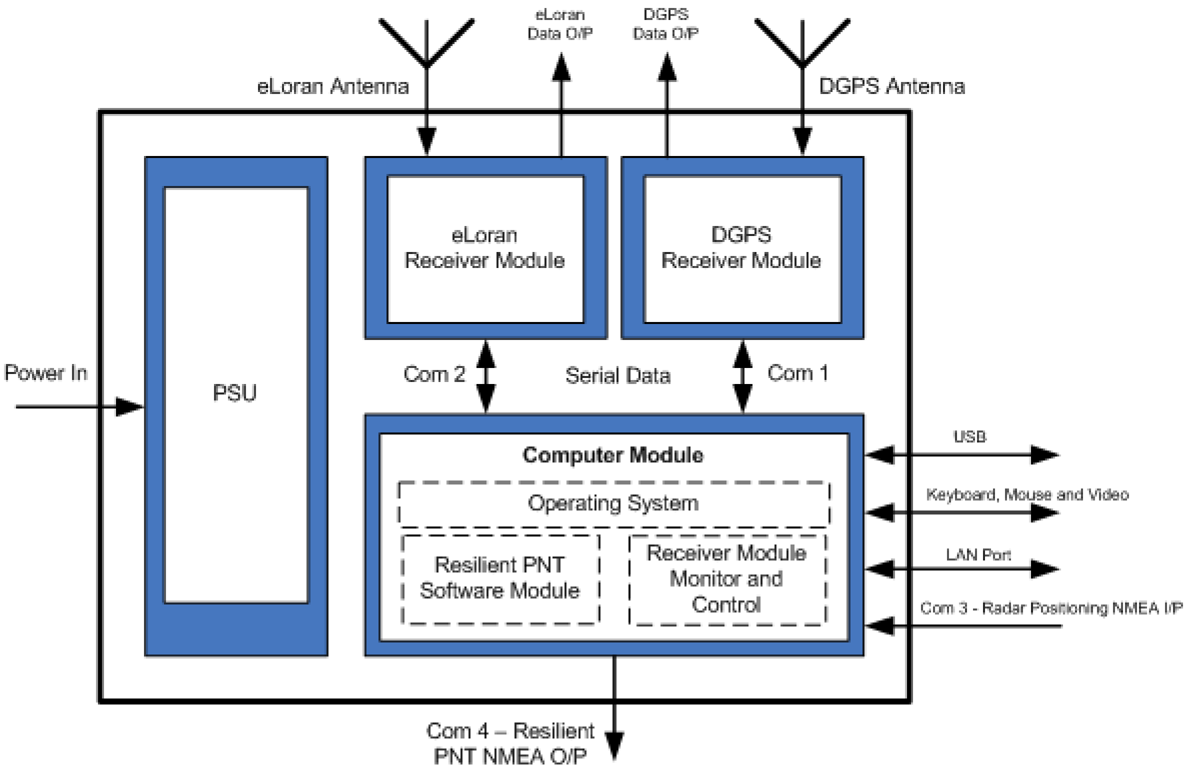


Figure 5.1 – Schematic of the ACCSEAS MSPS receiver and its internal components.

Therefore the following tests are planned to ensure the correct operation of the MSPS receiver:

- Initial inspection test
- Power on test
- Computer functionality test
- eLoran module test
- (D)GPS module test
- Connectivity tests
- GLA algorithm installation test
- Resilient PNT functionality test

The following section outlines each test separately and provides a structured test approach.

During development and testing, training needs will be identified and these will be captured in the ACCSEAS training needs document.

5.1.1.1 Initial inspection test

This test is quite straightforward, but an important one in order to confirm the hardware has not been damaged in transit. Before progressing with any tests, the unit should be reviewed to ensure there are no signs of damage and that all of the necessary data ports are present and free of obstruction. In addition, the various labels on the unit should be clear and easily read.

Physical damage

Test 1.1 – Are there any signs of physical damage to the receiver?

Ports

The receiver should have ports on the front and rear of the unit. The unit should have the ports and LEDs on the front and rear as outlined in Figure 5.2 below.

Therefore on the front of the unit should be 8 LEDs and 2 USB ports. On the rear should be a multi-core connection for the combined eLoran and MSK (DGPS radiobeacon) antenna, a TNC connection for the GPS antenna, two BNC connectors for the GPS and eLoran PPS outputs and five RS232 9-pin d-type ports for data in and out. In addition to this there should be the ports associated with the computer module, i.e. DVI, USB, LAN and PS2 connectors. Finally there is a power connector.

Test 1.2 – Are all of the required connections in place and free of obstruction?

Labelling

The receiver should have the correct labelling and that labelling should be clearly visible and easily read. Labels should match those indicated in Figure 5.2 below, with the exception that the “alternate” label on the front should read “external”.

Test 1.3 – Are all of the required labels in place and clearly readable?

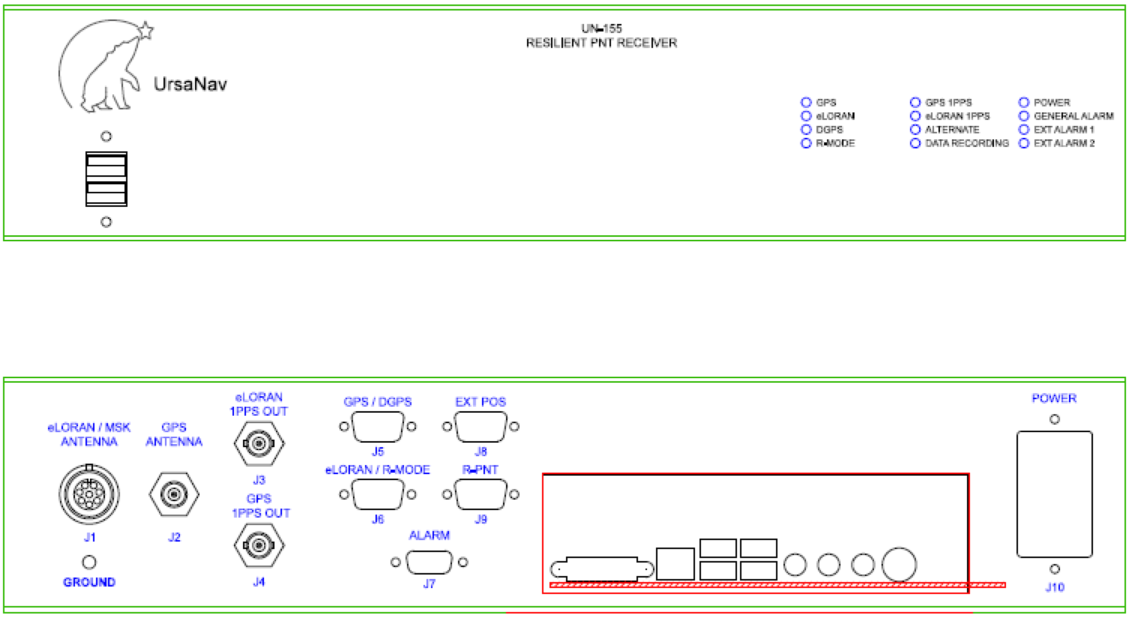


Figure 5.2 – Example layout of ports on the ACCSEAS MSPS receiver.

5.1.1.2 Power on test

These tests confirm that the internal power distribution cabling is correctly installed and configured. With the receiver power connected and switched on, the Power LED on the front of the receiver should be illuminated.

It should also be possible to hear the receiver cooling fan. Note the hard disk inside the unit is solid state and therefore will not make a sound.

Test 2.1 - With the power connected and the unit switched on, is the Power LED illuminated?

5.1.1.3 Computer functionality test

In order to test the functionality of the on board computer, a keyboard, monitor and mouse need to be connected to the receiver. Once connected, it should be evident that the PC is working if the Windows operating system is visible.

Switch the receiver on and ensure that the onboard computer boots and the operating system loads.

Test 3.1 – Check that the computer operates and the operating system is available for use.

Double click on the Elegant software and ensure it loads. Initially it will not have enabled any of the receivers and the user is directed to read the operating manual, located on the desktop.

Test 3.2 – Load the UrsaNav Elegant software and confirm it is possible to enable the eLoran receiver and that data flows on the screen.

Using a second computer and the Microsoft HyperTerminal software, confirm that eLoran data is available on the eLoran output serial port on the back of the receiver.

Test 3.3 – Confirm that eLoran data is available on the “Eloran” serial port at the rear of the unit.

Enable the GPS receiver module and the Differential module and confirm that data flows on the screen.

Test 3.4 – With the UrsaNav Elegant software loaded, confirm it is possible to enable the GPS receiver module and data flows on the screen.

Again, using a second computer, ensure GPS data is provided as an output via the GPS serial port on the rear of the receiver.

Test 3.5 - Confirm that GPS data is available on the "GPS" serial port at the rear of the unit.

5.1.1.4 eLoran receiver module test

This test is due to confirm that the eLoran receiver module is working correctly. It will require the connection of the eLoran antenna which will need to be sited in an appropriate location, preferably outside (in preparation for later tests).

Using the UrsaNav Elegant software, confirm that eLoran data is present and that a position is provided. The position accuracy will differ depending on location and proximity to a differential-Loran reference station.

Test 4.1 – Confirm an eLoran position is provided.

The software would also allow for eLoran data to be logged locally within the receiver unit. Using the options within the eLoran section of the Elegant software, save data locally for a short period. While data is being saved the "LED" icon on the software will change colour, but the LED on the outside of the receiver may not, as that changes colour to indicate all data is being recorded.

Test 4.2 – Check that it is possible to extract and record eLoran data.

5.1.1.5 (D)GPS receiver module test

Connect the GPS antenna and position appropriately, preferably with a clear sky view. When complete, enable the GPS receiver in the software and ensure data is seen to flow across the screen. Confirm the position from either the GGA or RMC NMEA data message. The position should be within 10m of the users location.

Test 5.1 – Confirm a GPS position is provided.

Using the software provided, enable data logging for a short period and confirm the data was logged on the local hard disk. The LED icon on the Elegant software will turn green for the GPS data section, but again the external LED on the receiver unit will stay red until all data is set to record.

Test 5.2 – Check that it is possible to extract and record GPS data.

With the eLoran and GPS antennas connected, enable the DGPS functionality with the Elegant software. After a short while, it should show completed data fields and the unit should automatically move from GPS to DGPS. When DGPS data is available, via the software, set it to record a short amount of data to the local hard disk and confirm it was recorded correctly.

Test 5.3 – Check that it is possible to enable DGPS functionality & log DGPS Data.

5.1.1.6 External input connectivity test

These tests will need an additional source of NMEA data, either a different receiver or pre-recorded NMEA data streamed from a second computer. Connect the NMEA data to the

"External" Serial port on the rear of the unit. The "External" section of the Elegant software should then be enabled and the NMEA data messages should be visible on the screen.

Test 6.1 – Input of data from external source

As with previous tests, set the external data to be recorded for a short period and confirm it was successfully recorded to the local hard disk.

Test 6.2 – Check that it is possible to record external input data.

5.1.1.7 GLA algorithm installation test

This section of testing ensures that the GLA resilient PNT software and the Matlab™ runtime environment can be installed on the computer board within the receiver and that the software can be configured to monitor the data from the different PNT sources.

The first task is to install a copy of the Matlab™ runtime environment onto the computer module. Ensure this is the correct version of the runtime environment as advised by GLA.

Test 7.1 – install the Matlab™ runtime environment on the PC without any warnings or errors.

Next install the GLA resilient PNT algorithm software. This software is a standalone executable and therefore should be copied from the original source to the program_files/resilient PNT/ directory. Once copied across, add a shortcut to the desktop and run the software.

Test 7.2 Install the GLA resilient PNT software and confirm it runs without warning.

Next configure the software to expect data from the eLoran and DGPS receivers via either the COM ports or the IP stream, as per guidance from GLA.

Test 7.3 Confirm the software is able to open the necessary COM ports or IP streams in order to monitor the performance of the eLoran and DGPS data.

5.1.1.8 Resilient PNT functionality test

For this test the resilient PNT receiver should have all of the resilient PNT algorithm software, loaded and configured to expect data from the different inputs as available.

To test the functionality, ensure that the unit is running with good eLoran and DGPS data. If this is the case, the eLoran GPS and DGPS data LEDs on the front panel should all be green and the 1PPS LEDS should be flashing. If data is being recorded from all available inputs and the resilient PNT output then the recording LED will also be green.

Remove the GPS antenna connection to simulate the loss of GPS and monitor the software and the LEDs on the front of the receiver unit. The software should alert to show that the resilient PNT output has been changed from DGPS to eLoran and there may be an alert to the loss of differential. The LED for resilient PNT should have turned green while the GPS LED should have turned red.

Test 8.1 – Remove the GPS antenna connection and confirm the receiver detects the loss of GPS and the output is changed from GPS to eLoran.

5.2 MSPS data in the EPD

The output of the receiver can be connected as a direct input to the EPD. The following prototype NMEA message has been developed within the project to convey resilient PNT information to the EPD.

$PRPNT,1.0,1,A,008.5,005.3,003.1,116*2A

$PR = PRoprietary talker ID, PNT = Position, Navigation and Timing

1.0 = Sentence version number (may be subject to change pending software development)

1 = PNT Source to use (1 = GPS 'GPRMC', 2 = eLoran 'ELRMC', 3 = Radar 'RDRMC' etc… 0 = do-not-use flag)

A = GPS Jamming Flag A-ok; J=Jamming; S=Spoofing (future addition)

008.5 = HPL in meters (8.5m), if this breaches the HAL, will set the validity flag to 'V' for corresponding navigation 'RMC' sentence.

005.3 = Error-ellipse major axis (5.3m), for eLoran this is equal to the HAL

003.1 = Error-ellipse minor axis (3.1m)

116 = Angle of ellipse major-axis from True North.

*2A = usual bit-xor checksum

The EPD uses this data, along with other inputs to provide information to the mariner as per Figure 5.3. The ellipse shown in the lower right of the display, overlaid with the vessel's outline, indicates the current position error and will change size to reflect the performance of the position source used. If GPS becomes unreliable or is lost, the EPD will be informed of the change in source by the receiver and will flag this to the mariner and update the resilient PNT section of the display.

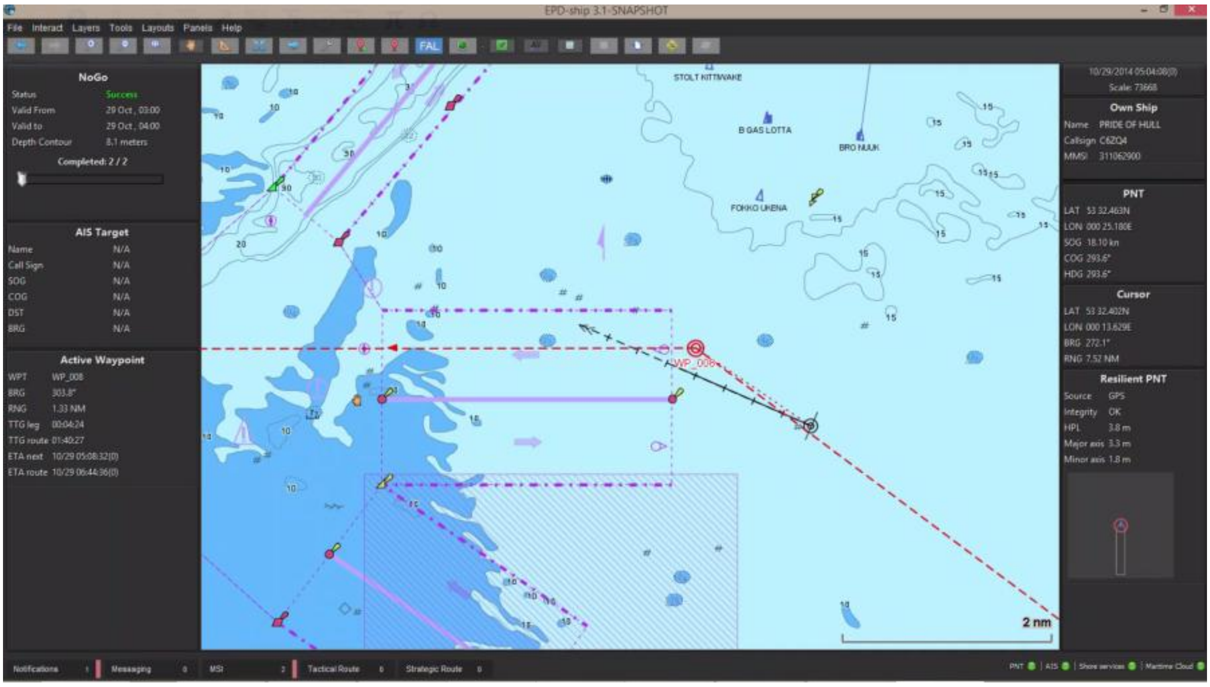


Figure 5.3 – A screen capture of the EPD with resilient PNT data provided.

5.3 GPS Jamming Tests

Resilient positioning, navigation and timing information is a critical component of e-Navigation, without resilience in positioning and timing, many other e-Navigation services would not function and the safety of the mariner would be degraded.

The effect of losing GPS on a modern vessel was demonstrated by the project in 2013 when a GPS jamming trial was conducted on the GLA vessel THV Galatea. The project website contains a video of the trial, but it is clear that many of the bridge systems rely or use GPS derived data.

During periods of GPS service disruption, whether caused by intentional or unintentional means, the accuracy of the reported GPS position may change, potentially quite dramatically. During low power GPS jamming trials it was possible to observe erroneous GPS positions and reported speeds ranging from a few knots to many hundreds of knots. Indications of small variations in position are serious in that they could be believed and not identified as being incorrect, leading to the mariner or bridge equipment to continue to use this data. Large scale changes should be easier to spot.

When the effect is sufficient to stop GPS receivers from providing data, the many different systems on the ship which use GPS will enter an alarm state. This includes the main (and backup if present) GPS receiver, the Electronic Chart but also includes other less expected systems like the radar and the gyrocompass, which use GPS data for auxiliary functions. The many systems alarm together creating a cacophony of noise which can distract the mariner.

In order to enhance e-Navigation and the mariners' safety, the removal of erroneous data and the alarms is important and this is the aim of resilient PNT. The receiver unit described in this section has been developed based on and evolution of the equipment used during the 2013 trial. As the video shows, when the system was enabled, it detected the effect of the GPS jammer on the reported GPS position and, when a safety threshold was exceeded, it alerted the mariner and switched from providing GPS data to eLoran data. This data was fed to the bridge systems and resulted in no alarms and enabled the vessel to continue its operations safety and seamlessly.

6 Training Requirements

The following training needs have been identified. These will be described further within the training needs report.

This section briefly outlines a structured regime for training stakeholders, including the mariner, on the Multi-Source Positioning Service (MSPS).

- The rationale for providing Resilient PNT
    - The widespread use of GNSS (particularly GPS) within ships' systems
    - The vulnerabilities of GNSS including historical evidence of real-life events and occurrences of outages and disturbance effects
    - The level of integration of GNSS aboard typical vessels
    - General awareness that the reported position contains errors

    - A description of the use of PNT within various e-Navigation services

- Options for sources of Resilient PNT
    - eLoran
    - R-Mode – AIS and MF
    - Radar Absolute Positioning

    - Signals of opportunity
    - Inertial systems
    - Establishing a business case for options

- An introduction to the Multi-Source Positioning Service
    - Technical Services
    - Architecture
    - Example design structure
    - An outline of its attributes and capabilities
    - Operational services
    - Multi-Source Receivers
    - The possible future evolution of the service

- Engineering officer training on how such systems work, their limitations and how to fault find with them.
- Navigating officer training
    - Training for navigating without GNSS
    - Training for using resilient PNT systems, what they can do and how to use them

7 Constraints and Issues

The accuracy, availability, continuity and integrity of the MSPS depend on the amount of infrastructure provided by maritime nations in the NSR. Sufficient numbers of ranging signals of sufficient quality are required to support the backup systems contained within the MSPS.

In the absence of a European Radio-Navigation Plan (ERNP) administrations are free to decide what systems they intend to provide in their responsible area. The decision about which system to support should be made following a carefully constructed Business Case, which would involve the analysis of the various options available and a comparison of the cost-benefit ratios of each one.

8 Future Evolution of the Service

This section briefly presents some ideas for expansion of the service.

8.1 Collaborative Navigation

With “Collaborative Navigation” the aim would be to take advantage of the availability of the Maritime Cloud to share radionavigation system calibration data (for example eLoran ASFs) with shore-side databases and other vessels. The ACCSEAS Multi-Source Receiver contains all the necessary components to make propagation data measurements that are vital to the functioning of terrestrial radionavigation systems. This data may be collected during normal operations of the receiver installed aboard vessels going about their business. Data collected may be automatically "dumped" to a central repository, collated, processed and then disseminated as updates to existing databases, perhaps on scheduled monthly or quarterly updates.

It may also be possible to share calibration data between vessels as they pass one another; one into and one out of a region of leg of the RTM.

8.2 Expansion with ARIADNA Functionality

The inclusion of aspects of the EU Framework 7 project ARIADNA could be performed under a future ACCSEAS 2 programme of work, including expanding the use of the HPL computation to affect the "volume" of the vessel.

8.3 Future Standards Development

See Appendix B.

9 References

[1] 'DEVELOPMENT OF AN E-NAVIGATION STRATEGY IMPLEMENTATION PLAN – Proposed architecture for the provision of resilient PNT data', SUB-COMMITTEE ON SAFETY OF NAVIGATION 58th session, Agenda item 6, NAV 58/6/1, 30 March 2012.

[2] 'FEASIBILITY STUDY OF R-MODE COMBINING MF DGNSS, AIS AND ELORAN TRANSMISSIONS', Gregory Johnson and Peter Swasxek, Prepared for German Federal Waterways and Shipping Administration, 25th September 2014.

[3] 'RADAR POSITIONING – TRIALS RESULTS AND FEASIBILITY ANALYSIS', Nick Ward, ACCSEAS WP5 Technical Report, V1.0

[4] 'Implementing e-Navigation in the North Sea Region – the ACCSEAS Contribution (ACCSEAS e-Navigation Architecture Report)'

Annex A – Proposed MSPS Attributes

Table 3 lists potential attributes associated with the MSPS; these are suggestions only aimed at promoting discussion within the wider community. The aim within ACCSEAS is not necessarily to implement all of the attributes listed in the table. Neither is it assumed that the list is complete. The version of the MSPS implemented for ACCSEAS will provide only those output attributes required for demonstrating the ACCSEAS demonstrated services. These are listed separately in Section 4.

Attribute	Definition	Value Range	Source	Portrayal
PNT Data Processor				
Expected Accuracy (MSPS_1)	The degree of conformance between the estimated or measured parameter of a craft at a given time and its true parameter at that time. Absolute accuracy (Geodetic or Geographic accuracy). The accuracy of a position estimate with respect to the geographic or geodetic co-ordinates of the Earth. This is an estimate based on coverage prediction.	0.5m to 1km	Estimated PNT System capabilities through coverage prediction. RTM	Estimated 95% circle around vessel. Static value associated with vessel location or current element of Route Topology Model within which vessel resides.
Expected Integrity (MSPS_2)	The ability to provide users with warnings within a specified time when the system should not be used for navigation. *Integrity risk* – The probability that a user will experience a position error larger than the Horizontal Alert Limit (HAL) value without an alarm being raised within the specified time to alarm at any instant of time at any location in the coverage area.	0 to 100% Resolution:0.1%	Estimated PNT System capabilities through coverage prediction.	Colour coded indicators on ECDIS. Audible alarms. Static value associated with vessel location or current element of Route Topology Model within which vessel resides.

Expected Availability (MSPS_3)	The percentage of time that an aid, or system of aids, is performing a required function under stated conditions. Non-availability can be caused by scheduled and/or unscheduled interruptions. Signal availability. The availability of a radio signal in a specified coverage area. - System availability. The availability of a system to a user, including signal availability and the performance of the user's receiver.	0 to 100%	Estimated PNT System capabilities through coverage prediction.	Numerical percentage value. Static value associated with vessel location or current element of Route Topology Model within which vessel resides.
Expected Continuity (MSPS_4)	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.	0 to 100%	Estimated PNT System capabilities through coverage prediction.	Numerical percentage value. Static value associated with vessel location or current element of Route Topology Model within which vessel resides.
Coverage (MSPS_5)	The coverage provided by a radionavigation system is 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.	Dependent on attribute of interest and limits of requirements for voyage phase.	RTM attributes	Presentation of attributes MSPS_1 to MSPS_4 associated with RTM leg.
Position (MSPS_6)	Geographical position in latitude and longitude with respect to WGS-84	Latitude: ±90° Longitude: ±180° Degrees and decimal	Multi-Source Receiver	Numeric data and charted graphical position shown as isosceles triangle, with

		degrees wrt WGS84 ellipsoid		longest two sides of triangle oriented towards ship's heading (MSPS_15).
Horizontal Protection Level(s) (HPL) (MSPS_7)	An estimate of the accuracy error performance based on models, and error bound estimates from a system error budget. Multiplied by appropriate K factor for integrity level. Maintained for each system.	0 to 2500m Resolution:0.1m Tabular	Multi-Source Receiver	Ellipse surrounding triangle portrayed in MSPS_6, or overlaid with circle of MSPS_19. Expressed as semi-major and semi-minor axes of the ellipse
PNT Source Indicator (MSPS_8)	An indication of which source of PNT is being used at the current time	ON / OFF	Multi-Source Receiver	Textual description on ECDIS, or radio button display
Captain's Risk Level (MSPS_9)	Derived from VNS.	Low, moderate and high	Captain's manual input	Parameters included in volume
GNSS Interference Detected (MSPS_10)	Flag to indicate that jamming or interference has been detected on GNSS	ON / OFF	Multi-Source Receiver	Onscreen and audible alarm.
Vessel Dynamic Information				
Course Over Ground (MSPS_11)	The actual path of a vessel with respect to the seabed, measured in degrees. Course may be relative to true north (true course) or magnetic north (magnetic course).	Decimal degrees from WGS84 North Resolution: 0.1°	Multi-Source Receiver	Textual information. Direction line superimposed on vessel isosceles

				triangle mark (MSPS_6)
Speed Over Ground (MSPS_12)	This is the distance between successive fixes divided by the time between fixes. The actual speed a navigation receiver is moving over the surface of the earth.	Knots Resolution: 0.1kt	Multi-Source Receiver	Textual information. Length of direction line superimposed on vessel triangle mark (MSPS_11)
Rate of Turn (ROT) (MSPS_13)	Rate of Turn, the speed at which a ship, vessel, or unit is turning at, or is capable of turning at, measured in degrees per second.	Degrees per minute. Resolution: 0.1°	Multi-Source Receiver	Textual information.
Cross Track Error (MSPS_14)	The distance from the vessel's present position to the closest point on a great Circle line connecting the current waypoint coordinates. The component of the Vessel Technical Error perpendicular to the intended track.	0 to 2500m Resolution: 0.1m	E-Navigation Prototype Display. Computed from HPL	Textual information.
Heading (MSPS_15)	The direction in which the boat's bow is pointing at any given time.	0 to 359° wrt WGS-84 ellipsoid Resolution: 0.1°	Multi-Source Receiver	Textual information. Direction in which isosceles triangle is pointing (MSPS_6).
Maneuverability (MSPS_16)			VNS software	
Maximum Dynamic Trim (MSPS_17)	Calculated from Wave Box. VNS consideration. Future placeholder.	N/A	VNS software	N/A

Wave Box (MSPS_18)			VNS software	
Horizontal Alert Limit of Service (MSPS_19)	The accuracy error limit at which an alert is to be presented to the mariner/user.	Metres 0 to 2500m Resolution: 1m	Determined from published IMO requirements depending on particular voyage phase or intended maneuver. Also influenced by intended ACCSEAS e-Navigation services.	Textual information as required. Circle drawn on display key.
Available Services (MSPS_20)	List of spectrum of e-Navigation services and/or portfolios available at current position, with their RNP requirements; accuracy, integrity, availability and continuity.	N/A	Sub-set of Maritime Service Portfolio.	Textual menu item.
Table of currently active services (MSPS_21)	List of services currently in use by the vessel, with their RNP requirements; accuracy, integrity, availability and continuity.	N/A	EPD	N/A – Internal parameter.
Table of Integrity Alerts (MSPS_22)	List of integrity alerts for each source of PNT. Appropriate with each service, should a problem be identified such as an integrity breach (HPL>HAL), an integrity alert shall be generated. This will inform the mariner, or other stakeholder, of the problem so that action can be taken, including the abortion of an operation or dissemination of the information along the command/management	Enumerated list of data structures; {PNT ID, Alert Limit, BreachFlag}	Multi-Source Receiver	N/A – Internal parameter.

	chain.			
Chart uncertainty (MSPS_23)	Uncertainty due to accuracy of horizontal positioning and vertical (bathymetry) measurement.	N/A	IHO Data Quality Working Group. CATZOG information Included in chart data as separate attributes.	N/A – Internal parameter.
Time stamps of data (MSPS_24)	The UTC time stamp applied to NMEA sentence data.	Resolution: 0.01 second	Multi-source Receiver	N/A – Internal parameter
Current service level (MSPS_25)	Voyage phase associated with performance requirements	Enumeration of Port Approach; Coastal, Ocean	EPD Instance of Route Topology Model	Textual
Vessel Static Information				
Own Vessel Length (MSPS_26)	Length – The distance between the forwardmost and aftermost parts of the ship. Length Overall (L.O.A.) – The maximum length of the ship Length at Waterline (L.W.L.) – The ship's length measured at the waterline	Metres Resolution: 0.1m	EPD	N/A Internal parameter
Own Vessel Beam (MSPS_27)	The width of the ship.	Metres Resolution: 0.1m	EPD	N/A Internal parameter
Own Vessel	The depth of water necessary to float the	Metres	EPD	N/A Internal parameter

Draft (MSPS_28)	vessel with its current load.	Resolution: 0.1m		
Own Vessel Height (MSPS_29)	Height of the vessel considering current draft.	Metres Resolution: 0.1m	EPD	N/A Internal parameter
Vessel Positioning Reference Point (MSPS_30)	Origin of vessel co-ordinate reference frame. For computation of Lever Arms between PNT source antennas.	N/A	N/A	N/A
Types of radio-navigation (MSPS_31)	Which radionavigation systems are installed?	Enumeration of GNSS; eLoran; Rmode;	Multi-Source Receiver	Numeric ID
Radio-navigation antenna Lever Arm(s) (MSPS_32)	Location of each radio-navigation antenna and type with respect to origin of vessel coordinate reference frame.	Array of lever-arm values from vessel positioning reference point, in X and Y co-ordinates (metres). Positive X coordinate in a direction forward of origin. Positive Y coordinate in a direction starboard of origin.	Multi-Source Receiver	N/A Internal parameters
Environmental Information				
Current	Direction and magnitude of current, sea or		Admiralty Total Tide?	

(MSPS_33)	river.			
Sea state (MSPS_34)	Current state of the sea.	??	??	??
Wind (MSPS_35)	Direction and magnitude of wind.	??	??	??

Table 3 – Potential Data Attributes of the Multi Source Positioning Service.

Annex B – Recommended Input to Standards Organisations

Adopting aspects of the Multi-Source Positioning Service will require consideration within the various standards bodies pertinent to maritime navigation. This section contains a list of such standards that may need to be considered either for updating or to be taken into consideration.

IMO – The International Maritime Organisation

The IMO sets the performance standards, based on user requirements:

Unification of Performance Standards for Navigation Equipment – A.575 (14).

Measuring noise levels at Listening Posts - A.343 (IX)

General requirements for GMDSS and electronic Navigation Aids - A.694 (17)

General requirements for Electromagnetic Compatibility (EMC) - A.813 (19)

A.819 (19)

A.529

A.815

ITU – The International Telecommunications Union

The ITU determines the technical characteristics and spectrum requirements.

Recommendation M.589-3 (08/01)

IEC – The International Electrotechnical Commission

The IEC provides test specifications for the onboard user equipment, based on output of IMO and ITU:

IEC 61108-1

IEC 61162

IEC 60945

IEC 61174

IEC 61075

RTCM – Radio Technical Commission for Maritime Services

Generates Minimum Performance Standards (MoPS) for receivers:

RTCM SC-127

RTCM SC-131

IALA – International Association of marine Aids to Navigation and Lighthouse Authorities

IALA sets operational and performance recommendations for service providers

In addition to making input to the above standards and regulatory documentation, other documentation will need to be created for new sources of navigation information, for example, R-Mode and radar absolute positioning.

Annex C – Terms and Acronyms

Acronym or Term	Definition	Notes
AIS	Automatic Identification System	VHF Time Division Multiple Access (TDMA) digital communication based vessel tracking system, operating on maritime VHF frequencies 161.075 and 162.025 MHz.
ASF	Additional Secondary Factor	Propagation delay corrections (in micro-seconds) for eLoran navigation signal propagation delays above the sea-water assumption
CATZOG	Category of Zone of Confidence	CATZOC allows a hydrographic authority to encode data against five categories (ZOC A1, A2, B, C, D) with a sixth category (U) for data which has not been assessed. The categorisation of hydrographic data is based on three factors (position accuracy, depth accuracy and seafloor coverage), as specified in IHO publication S-57.
EPD	e-navigation Prototype Display	ACCSEAS user interface based on a prototype, standalone, ECDIS. This may be ship based or shore (VTS) based.
FAL	Facilitation of Maritime Traffic	Information provided by the vessel or the vessel's agent prior to arrival in port. For example, Notice of Arrival and Pilot Requests
GMSK	Gaussian Minimum Shift Keying	A bandwidth efficient data modulation scheme used by AIS in the marine VHF radio frequency band
HAL	Horizontal Alert Limit	The maximum allowable error in the measured position – during integrity monitoring - before an alarm is triggered. In the MSPS this is assumed to be at the 99.999% probability level.
HPL	Horizontal Protection Level	An estimate of the total system positioning error at the 99.999% probability level. Note that this is a value that is greater than the typical accuracy requirements, e.g. IMO 10m (95%) for Port Approach, but is designed to be compared to the IMO Horizontal

		Alert Limit (HAL) for integrity monitoring purposes. The HPL is computed through the use of an integrity equation.
IALA	International Association of Aids to Navigation and Lighthouse Authorities	
IHO	International Hydrographic Organisation	
IMO	International Maritime Organisation	
IVEF	Inter VTS Exchange Format	
MF	Medium Frequency	That part of the radio frequency spectrum between 300kHz and 3Mhz. IALA radiobeacon DGPS operates at around 300kHz, and so is a MF system.
MSP	Maritime Service Portfolio	A catalogue of services available in an area.
MSI/NM (T&P)	Mariners Safety Information/Notices to Mariners (Temporary and Permanent)	An e-Navigation service intended to distribute Notices to Mariners and other maritime safety relevant information.
NCA	Norwegian Coastal Administration National Competent Authority	
NMEA	National Marine Electronics Association	

NOA&PR	Notice of Arrival and Pilot Requests	
RNP	Required Navigation Performance	
RTM	Route Topology Model	
SSN	SafeSeaNet	
UKC	Under Keel Clearance	The distance between the bottom of the keel of a vessel and the floor of the waterway.
VNS	Volumetric Navigation System.	For example that investigated under the ARIANDA project.
VTS	Vessel Traffic Service	
WO	Watch Officer	The officer on watch on the bridge of a vessel.