Maritime Integrated PNT System

Core element for safe ship navigation

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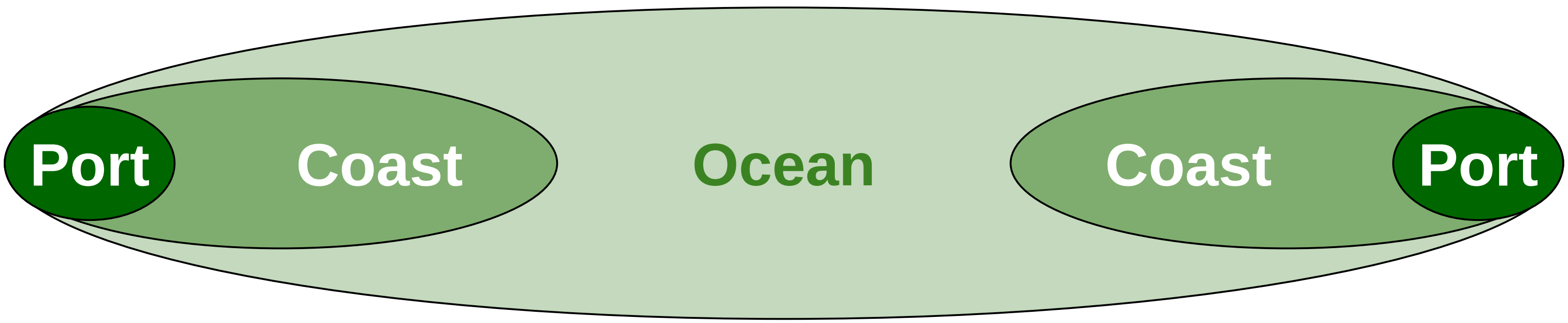
Maritime Integrated PNT System

= **overlay of satellite based, ashore and aboard components**, whose integrated use can ensure the accurate and reliable provision of PNT output data to applications during all phases of vessel navigation

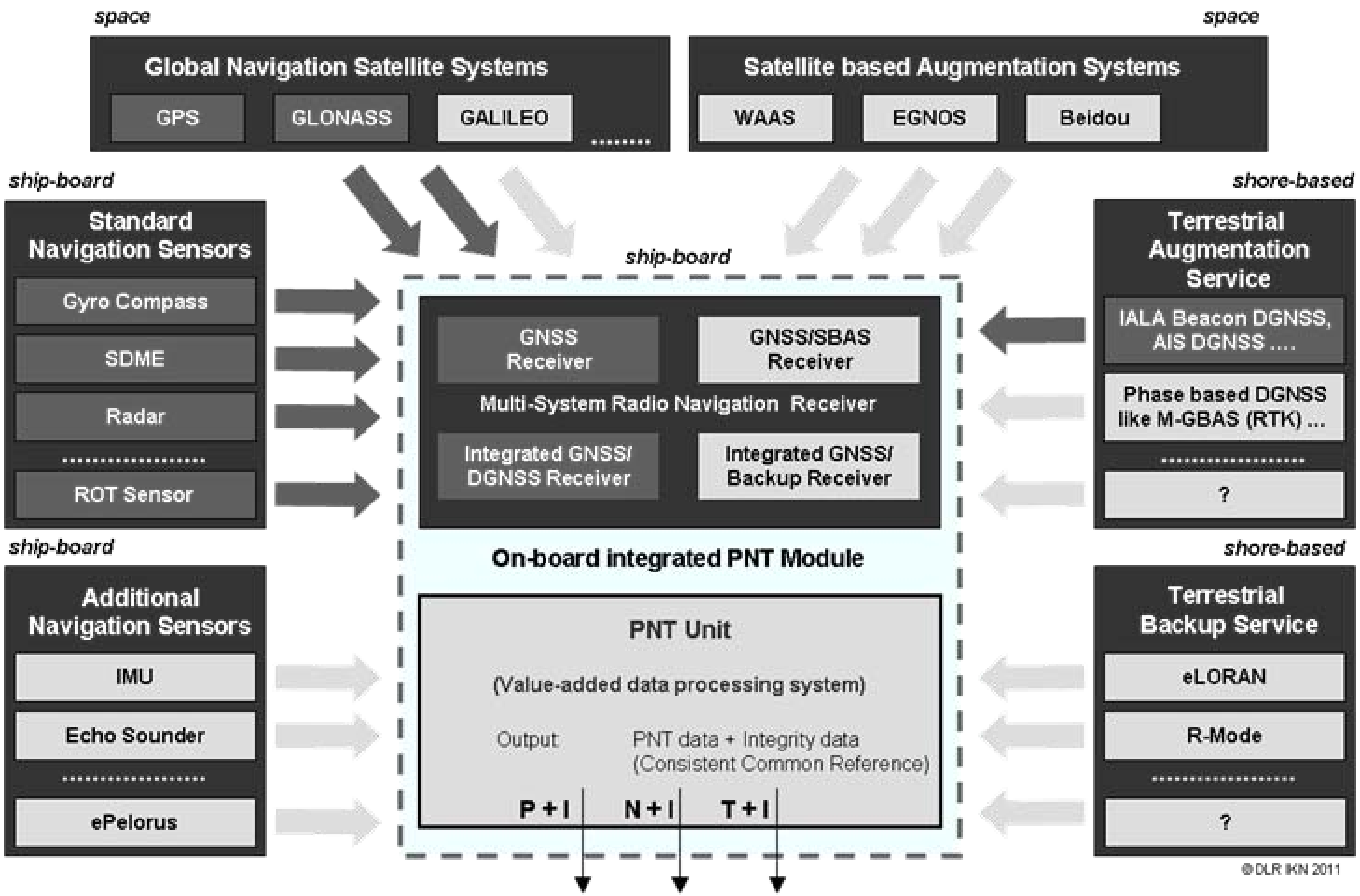


Accurate provision during changing accuracy requirements:

P	= Position data:	**Latitude, Longitude, and Altitude**
N	= Navigation data:	**Heading, SoG, CoG, Attitude….**
T	= Timing data:	**UTC**

Overview of PNT components

practice, existing, and future



Accuracy Requirements on future GNSS

IMO A.915(22): Minimum Requirements on future GNSS

	System Level Parameters				Service Level Parameters			
	Absolute Accuracy	Integrity			Availability (%) per 30 days	Continuity (%) over 3 hours	Coverage	Fix Interval[2] (s)
	Horizontal (m)	Alert Limit (m)	Time to Alarm[2] (s)	Integrity Risk (per 3h)				
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**
Automatic Docking	**0,1**	**0,25**	**10**	**10^{-5}**	**99,8**	**99,97**	**local**	**1**

1 - Continuity is not relevant for ocean and coastal areas
2 - More stringent requirements may be necessary for ships operating above 30 knots

Accuracy and Integrity Requirements for all PNT data ?

Identified User Needs

[IMO NAV56-WP.5 E-NAV report]

Examples

Identification of Reliability

- Automatically assessment of accuracy and integrity of hydrographical data, position fixing data, radar data, and other navigation relevant data;
- Graphical indication of assessment results;

Improvement of Reliability

- Reduction of failures and malfunction of electronic equipment
- Assessment and quantification of reliability

Alert Management

- Coordination and weighting of bridge alerts
- Support of decision making without undue diversion

Approaches

- Data and System Integrity
- Analysis
- Redundancy
- Backup
- Common Maritime Data / Information Structure
- Harmonised Meaning of Assessment Results
- ……

Integrity

Data Integrity

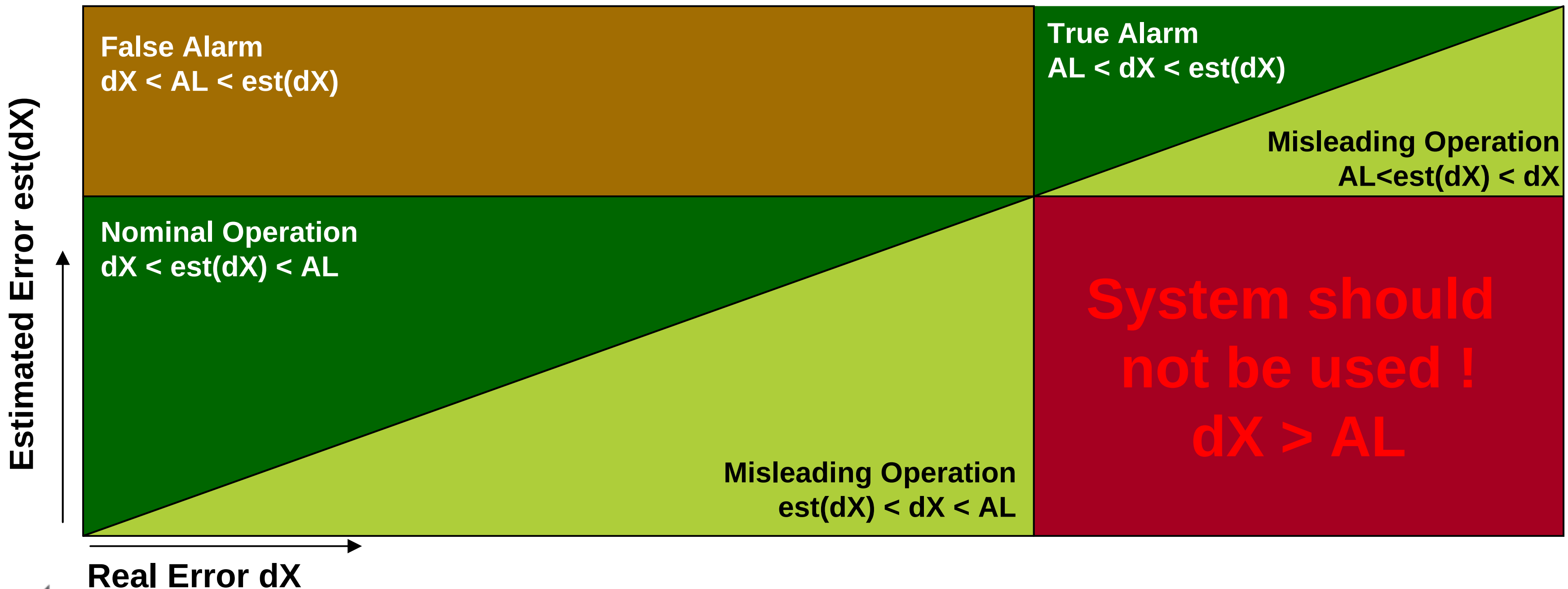
Desired data are provided completely, undisturbed and accurately.

$$X = \text{"}true\text{"} \quad or \quad \text{"}accurate\text{"}$$

System Integrity

Fulfillment of specified functionalities and related requirements.

$$State = F\left\{x_1, x_2 \ldots x_N\right\} = \text{"}reliable\text{"}$$



Objective of Integrated PNT System

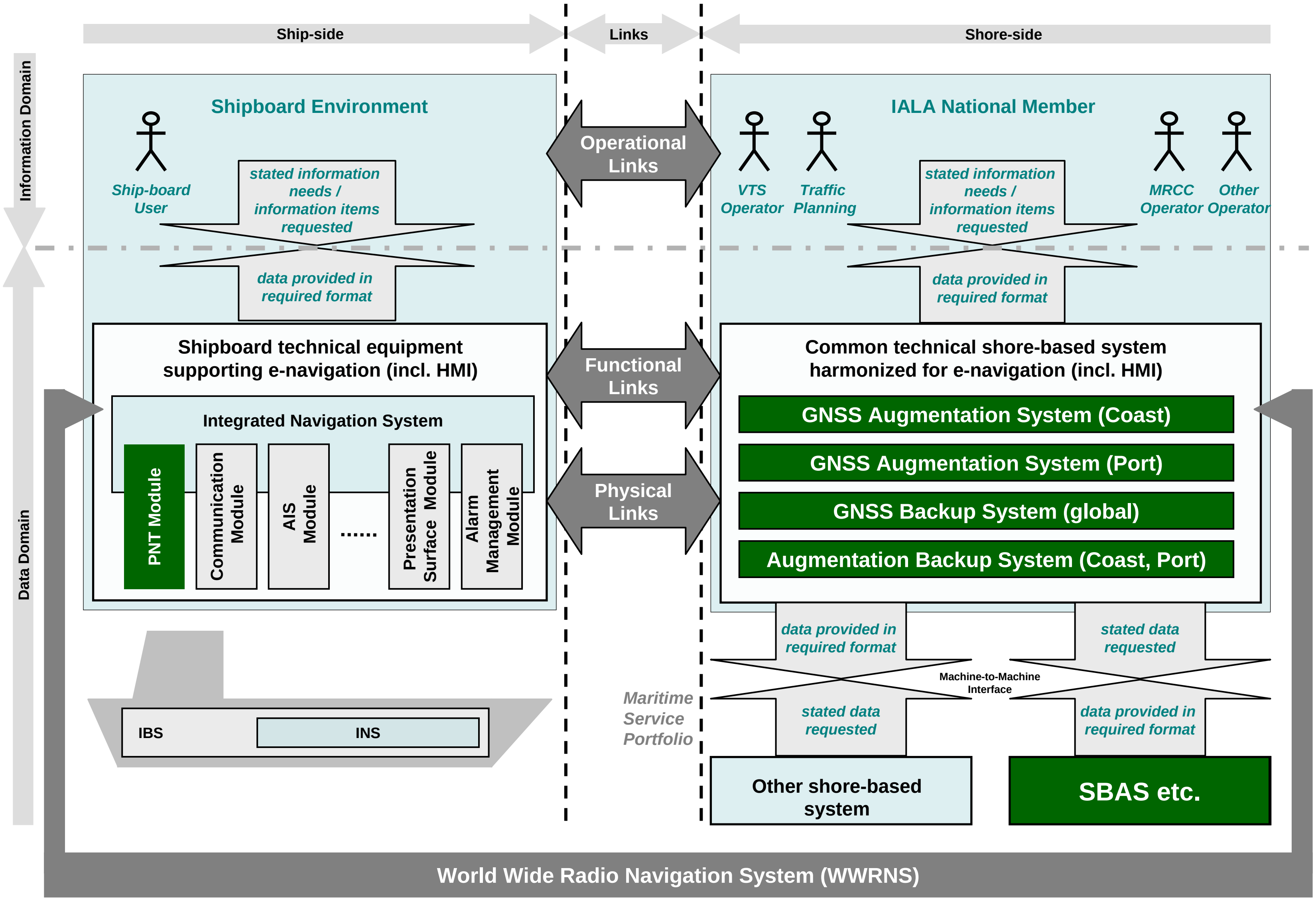
Accurate and reliable provision of

P	= Position data:	**Latitude, Longitude, and Altitude**
N	= Navigation data:	**Heading, SoG, CoG, Attitude….**
T	= Timing data:	**UTC**
I	= Integrity data:	**Accuracy assessment results of PNT data**
A	= Alert data:	**PNT&I data vs. requirements (paradigm shift)**

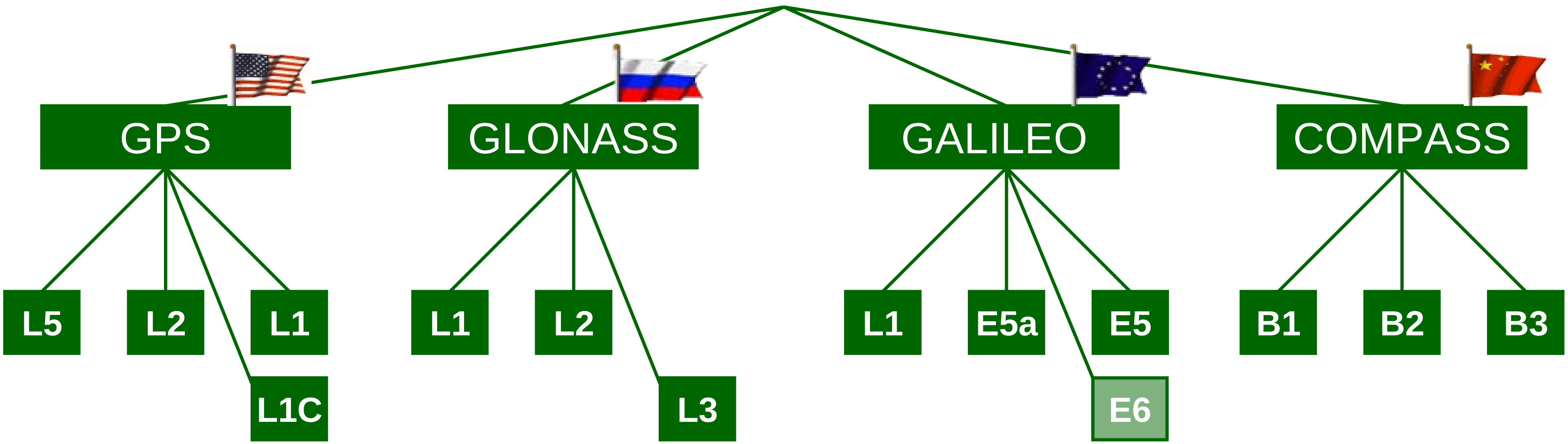
requires

- basis set of ship-board sensors and ashore services to ensure **complete provision of PNT data with desired accuracy** (basis functionality)
- redundant layout (multi-system and multi-sensor approach) to increase the **reliability of PNT data provision** and to ensure the **accuracy assessment** (integrity functionality)

E-Navigation Architecture & Integrated PNT System



The future redundant GNSS



Improved PT-data provision by:

- **Alternative usable single-frequency GNSS services**
- **Use of dual- and triple-frequency GNSS service**
- **Increased total number of available satellite navigation signals : → improved RAIM**

Modernisation of GNSS implicates:

- **substitution of GNSS receiver equipment (new signals, multi-system positioning)**
- **harmonised utilisation concept of signals to provide the "best" PT&I-results.**

GNSS Augmentation Systems

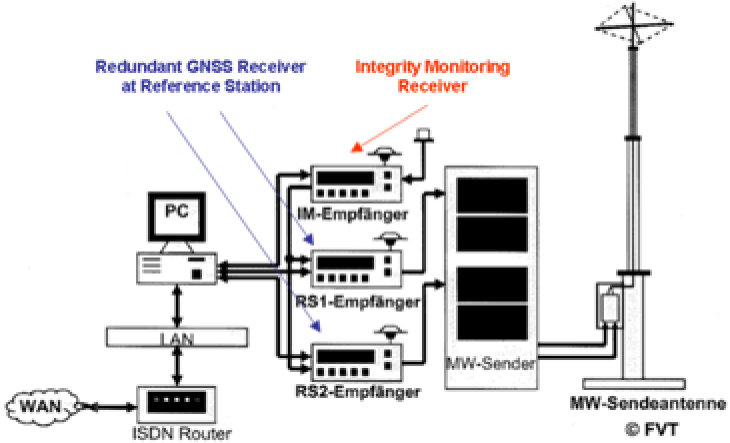
Aim

- Increase accuracy of GNSS based positioning by application of C-DGNSS
- Accuracy assessment (integrity) by monitoring of GNSS/DGNSS (LIM, FFIM)
- Provision of C-DGNSS related integrity information

Practice

IALA Beacon DGNSS (IALA R-121):

- Fulfilment of IMO coast requirements
- Provision of C-DGNSS corrections (PRC, RRC) and integrity information



Completion

AIS Base Station (IALA A-124):

- Provision of C-DGNSS and integrity corrections via AIS VHF Data Link (Message 17)

Channel capacity !

Modernisation of IALA Beacon DGNSS:

- Exchange and modernisation of GNSS receiver equipment
- Cost-efficient approaches for services (VRS concept)

Augmentation for port navigation:

- P-DGNSS based approaches (Rotterdam, Hamburg, FoHa Rostock, …)
- Standardisation is open task

GNSS Backup Systems

Aim

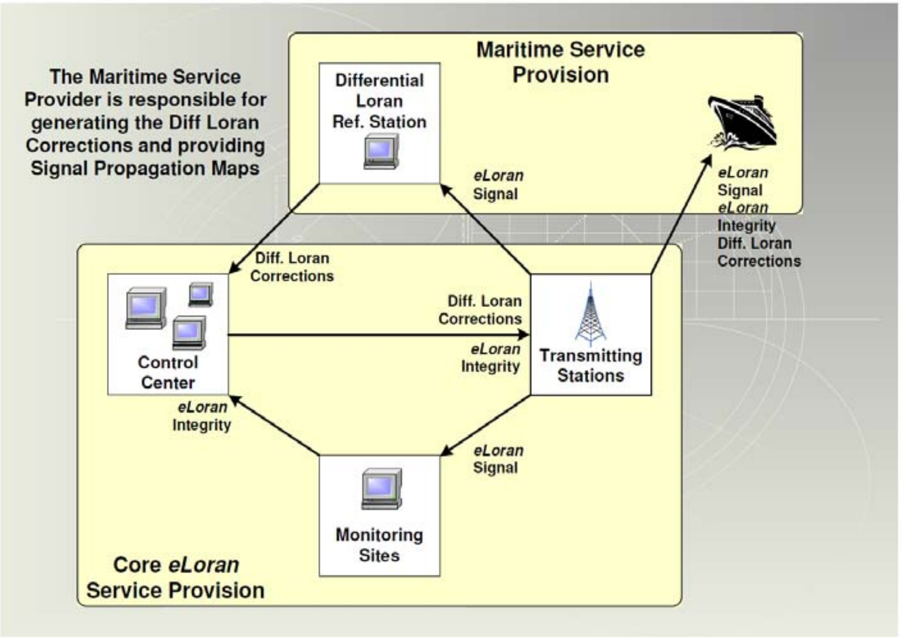
- **Compensation of GNSS vulnerability (interferences, jamming, and ionosphere) by GNSS independent determination of PNT data**

Candidate 1

eLoran

(**LO**ng-**RA**nge **N**avigation):

- **based on ground wave signal propagation (100 KHz)**
- **additional data channel to provide**
  - differential eLoran corrections to compensate ground wave propagation effects
  - warnings of anomalous radio propagation conditions
  - GNSS corrections
- **enables work of eLoran compass:**
  - requires H-field (Magentic Loop Antenna) for direction finding
  - offers heading determination better than 1°



Accuracy	Availability	Integrity	Continuity
0.004 – 0.01 nautical mile (8 – 20 meters)	0.999 – 0.9999	0.999999 (1×10^{-7})	0.999 – 0.9999 over 150 seconds

Source: International eLoran Assocoation, eLoran Definition Document (2007)

GNSS Backup Systems

Aim

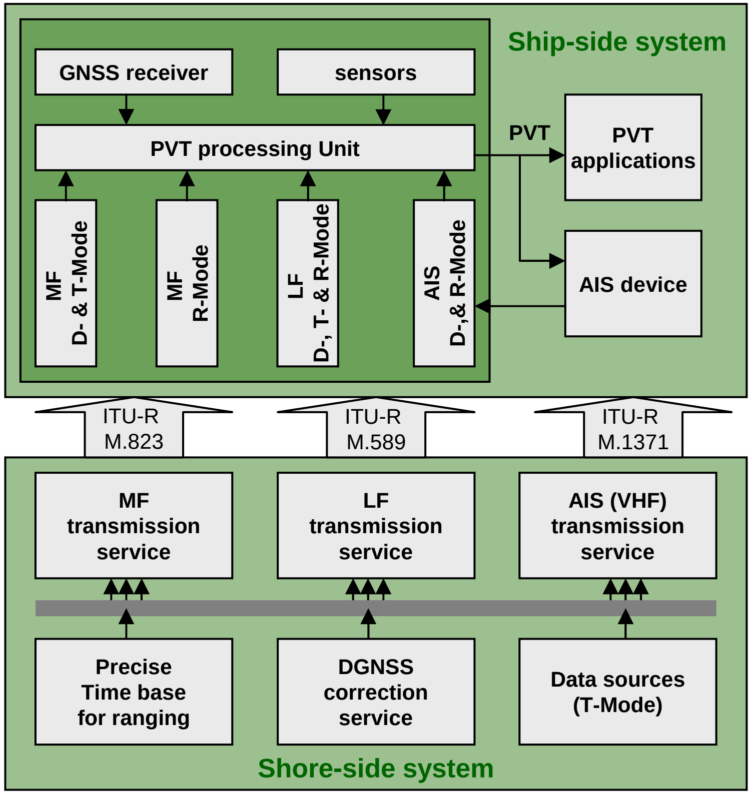
- **Compensation of GNSS vulnerability (interferences, jamming, and ionosphere) by GNSS independent determination of PNT data**

Candidate 2

R-Mode

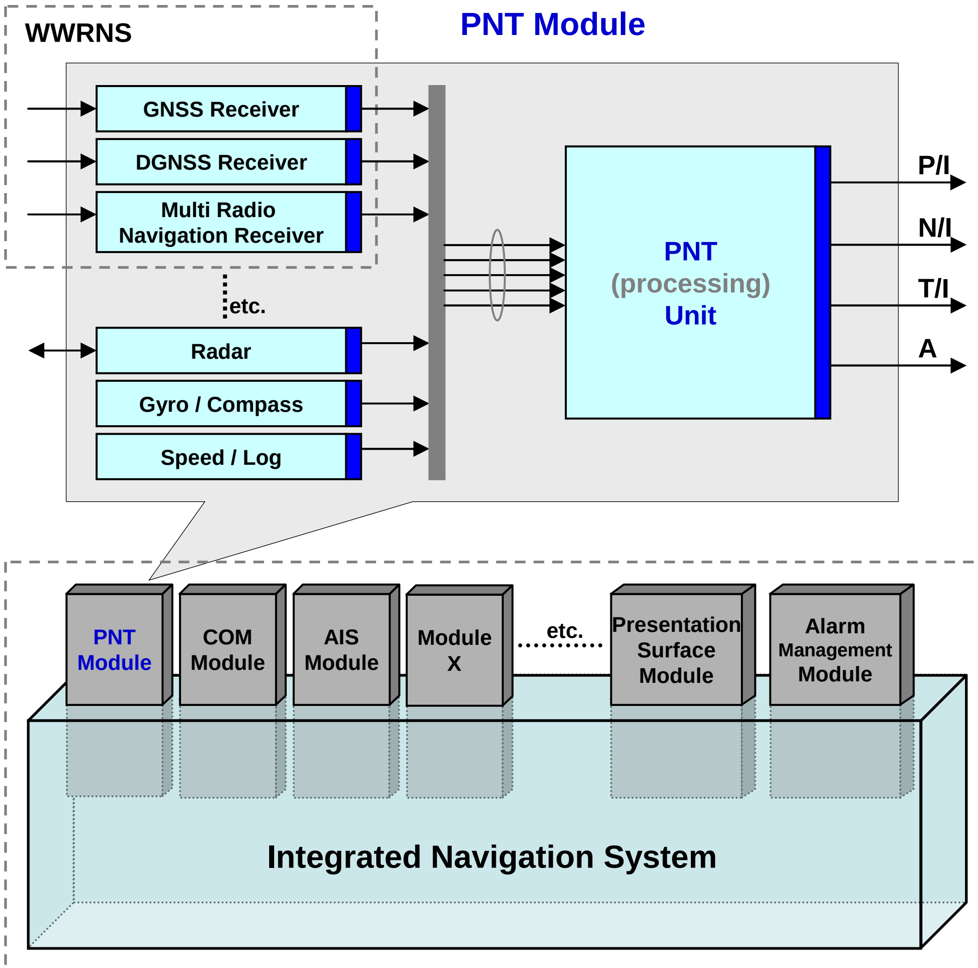
(**Ra**nging **Mode**):

- **based on existing IALA Beacon DGNSS and AIS service infrastructure (MF and VHF):**
  - requires modification of transmitting station
  - and extension with GNSS independent timing source
- **additional provision of timing information**
  - to derive distance measurements
  - to enable GNSS independent position determination based on multi-station approach
- **next steps**
  - feasibility study
  - field tests



Visionary concept:: Integrated Solutions for PVT (Hoppe, Oltmann)

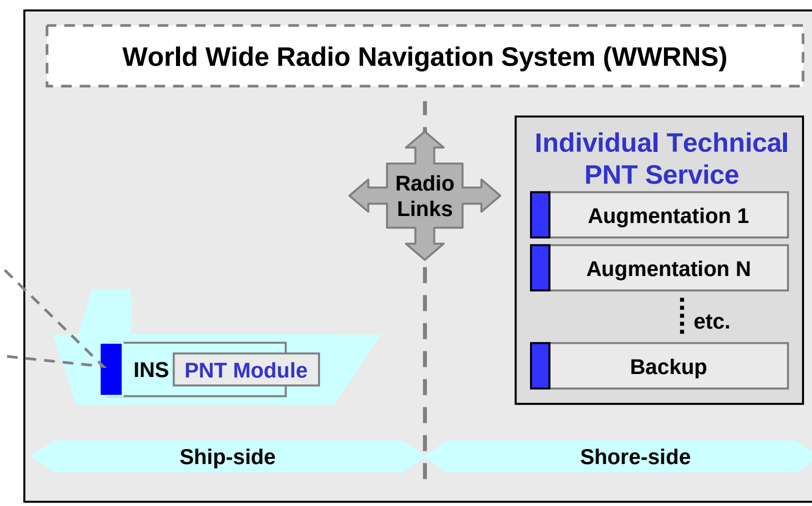
Onboard PNT Module



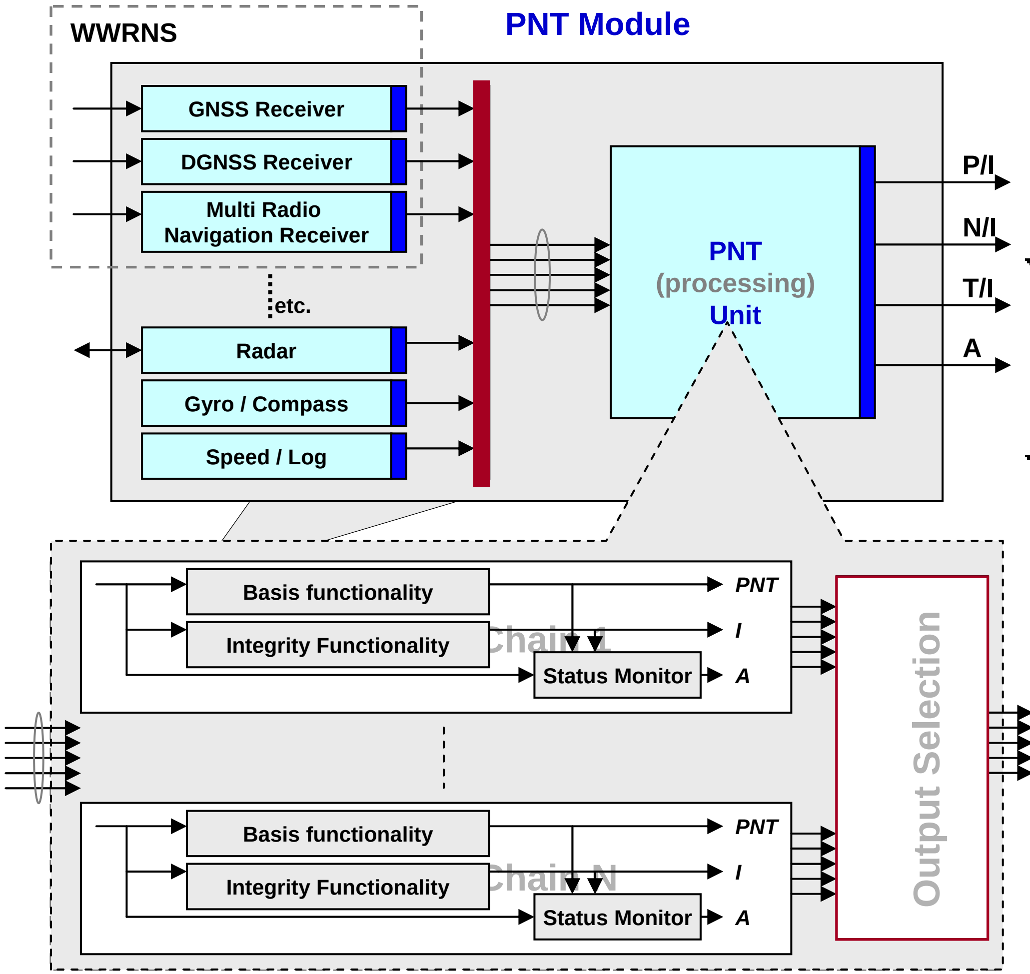
Legend:

- Product specification by Performance Standard
P/I - Position and Integrity Data
N/I - Navigation and Integrity Data
T/I - Time and Integrity Data
T/I - Alert Data

Integrated PNT System



Onboard PNT Module



- Creation of "true" redundancy by supported use of all PNT relevant sensor data including data of GNSS/DGNSS and future backup systems
- Introduction of parallel processing chains for robust PNT data provision under consideration of available augmentation and backup services
- Implementation of accuracy assessment (integrity functionality) per processing chain, if possible
- Performance controlled provision of "best" PNT output data
- Additional Provision of accuracy assessment results (integrity data)
- PNT relevant alert messaging for alarm management of Integrated Navigation System (INS) – paradigm shift

Safety, Risk and Integrity

Safety = System state free of intolerable risks

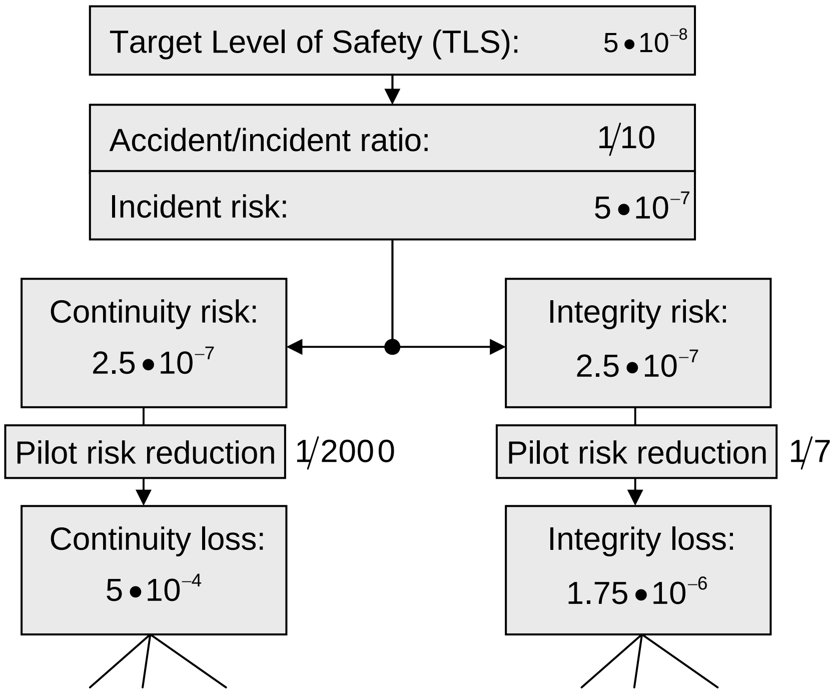
$$Risk = P_{Accident} \bullet Consequence(s)$$

Safety of Integrated PNT System
requires
risk distribution (fault tree analysis) & **management**

Project MarNIS:

First fault tree for port approach:

- Max. 1 accident per year induced by GNSS is tolerable considering estimated number of global port approaches
- Accident/incident ratio: only accidents result into consequences.
- Equal risk distribution on continuity and integrity risk?
- Risk reduction by human factor – tbc.
- Result of tolerable loss of continuity and integrity.



Risk distribution on components

Conclusions (1)

- The integrated PNT system is an **identified core element** for safe ship navigation to avoid collision and grounding
  - by resilient ship-side situation awareness
  - by reliable vessel traffic management

- **Automatically assessment of accuracy and integrity** of PNT data is an identified user need. This requires
  - **completion** of performance requirements for all PNT data
  - **redundancy** introduced by sensors, services, and processing techniques
  - **integrated consideration** of applicable complete processing chains regarding their achievable performance (error mitigation and propagation)
  - introduction of **performance key identifiers** for integrity monitoring and alert generation per processing chain
  - **harmonised meaning** of provided integrity information

- **Automatically assessment of accuracy and integrity** of PNT data enables the selection of the best PNT data at consistent common reference points.

Conclusions (2)

- **Detailed architecture design** of the Integrated PNT System is necessary
  - to describe the existing variety of **multi-sensor, multi-system and multi-service based processing chains** during berth to berth navigation
  - to assess the processing chains regarding the **accuracy of PNT data provision** and the **capability of integrity monitoring**
  - to enable **safety assessment analysis** and detailed identification of **technical gaps**
- The development of an **overall integrity concept** for the Integrated PNT System should be aimed
  - to improve **integrity monitoring** with **shared responsibilities** (ashore, aboard)
  - to enable scalability and **quantification of reliability**
  - to prepare an **operative risk management** inside the Integrated PNT System
- A paradigm shift from sensor related alert messages to output data related alert messages can support the **prioritisation and reduction of PNT relevant alarm messages**.