**Suggested approach for analysing different combinations of radionavigation systems.**

**1 BACKGROUND**

At the 59th Session of the IMO Sub Committee on Safety of Navigation (NAV 59), there was consensus in the e-Navigation Working Group on the need for Resilient Positioning Navigation and Timing (PNT).

This paper has been prepared for consideration of the IMO and provides a suggested approach to the assessment of systems and combinations of systems, which covers positioning aspects from radionavigation systems. This paper also introduces some new ideas on positioning that could be used to demonstrate how combinations of systems can improve resilience and performance.

It is generally accepted that GNSS (GPS in the short term) will be the primary position and timing sensor for maritime navigation. The increasing availability of more than one GNSS (GPS, GLONASS, BeiDou, Galileo and others) will increase resilience and integrity. However, all these systems share many failure modes, because they use the same frequency bands and have very low power signals. Therefore a higher level of resilience will be achieved by the use of complementary, dissimilar radionavigation systems, such as radar, or low frequency and high power terrestrial systems.

Some of these alternatives can be made available in the short to medium term, in parallel with the expansion of GNSS. Some have been demonstrated to work, but would need lengthy regulatory measures to become generally applicable. Others are likely to require considerable technical development before they can be accepted as practical and economic options for maritime use.

For example, eLoran is a proven system, meeting the IMO requirements for harbour and harbour approach (Williams et al, 2013). However, it is not widely deployed at present. Studies have shown that ranging mode (R-mode) on DGPS beacons and AIS could provide a backup to GNSS, in areas where coverage of such beacons is good (Johnson et al, 2014). This system has still to undergo practical testing and the necessary regulatory measures have still to be put in place. Absolute positioning using solid-state radar and enhanced radar beacons has been shown to work technically, but the regulatory process needed to implement it would be lengthy (Ward et al, 2014). Networks of shore based radars can be used to determine the position of the vessel and can transmit that position to the vessel.

The various combinations of options for achieving resilience would need to take into account the different stages of development, as illustrated in Figure 1.

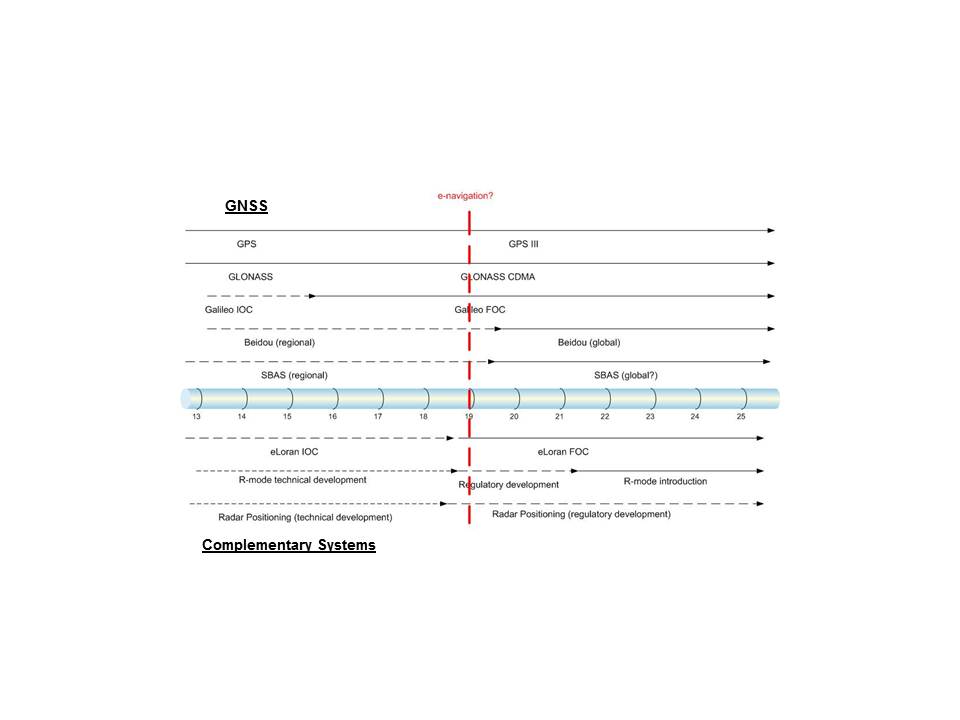


Figure 1. Indicative timeline for GNSS and complementary systems.

1. **APPROACH**

The first stage is to form a common understanding of what is meant by resilience. Resilience is defined as: “the ability of a system to detect and compensate external and internal disturbances, malfunction and breakdowns in parts of the system. This should be achieved without loss of functionalities and preferably without degradation of their performance” (NCSR1-9/2). This requires redundancy in data sources applied for positioning.

In order to assess the level of resilience achieved, the requirements for the application being considered will need to be known, including the effect of any degradation and its effect over time. It will be necessary to know how such a resilient system monitors the integrity of the available systems to decide on which data sources are used.

This paper provides a methodology for the assessment of the levels of resilience achieved by the use of individual and combined radionavigation systems. The methodology currently does not consider the ship system which decides on which system is used.

1. **Methodology**

The first stage is to define the requirements the radionavigation systems will be assessed against. In this case the requirements outlined in Resolution A.1046 (27) have been identified. However, it is recognised that other performance parameters may be required, depending on the intended application or user’s point of view. The approach proposed here is that in addition to the parameters of availability, accuracy, integrity and continuity set out in A.1046, the limitations of each system should be assessed, for example coverage, common mode failures, cross check ability, vulnerability to interference and operational status.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update rate |
| Ocean waters | 100 m 95% | 99.8 % | broadcast by MSI | - | 2 sec |
| Harbours, harbour approaches, coastal waters | 10 m 95% | 99.8 % | broadcast within 10 s | 99.97% in 15 minutes | 2 sec |

Table 1. WWRNS Requirements (A.1046(27)).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

Table 2: Assessment of system limitations

While Table 1 refers to IMO requirements, Table 2 is subjective and can be used to assess the limitations.

By comparing the different systems in tabular form, as defined in Table 1 and Table 2, assuming the data used is comparable, it should be possible to identify the approach which best suits the user’s requirements.

This approach considers requirements for SOLAS vessels, but could be extended for non-SOLAS requirements.

1. **Example**

**T**he following tables show example results and estimated limitations for GPS used on its own and then when combined with eLoran – Green indicates that A1046 requirements can be met, Red that they cannot. Further examples can be found in the Annex, however this is not an exhaustive list.

**GPS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update rate |
| Ocean waters | YES | NO | YES | N/A | YES |
| Harbours, harbour approaches, coastal waters | YES | NO | MSI - NO  RAIM - YES | YES | YES |

Table 3. GPS. Source: FRP 2012

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational status |
| Global | N/A | None | Vulnerable to interference | Operational |

**6.6 GPS/eLoran**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update |
| Ocean waters | YES | NO | YES | N/A- | YES |
| Harbours, harbour approaches, coastal waters | YES | YES | YES | YES | YES |

Table 8. GPS/eLoran. Source: Williams et al 2013

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
| Regional | Few (for example, solar storm and ship power failure) | Yes | GPS can be jammed quite easily. eLoran can be jammed but it requires considerable effort. | Not full operational |

From the examples given, it can be seen that the combination of systems is more resilient than the use of GPS on its own.

**REFERENCES**

1. Development of E-Navigation Strategy Implementation Plan – Review and Modernisation of the maritime position, navigation and timing system, NSCR1-9/2.
2. Williams P. and Hargreaves C. (2013). UK eLoran Initial Operational Capability. ION ITM 2013.
3. Johnson G. and Swaszek P. (2014). Feasibility Study of R-Mode using MF DGPS Transmissions. Prepared for the German Federal Waterways Administration under the ACCSEAS Project.
4. Ward N., Safar J., Grant A., Kojima T. and Mueller P. (2014). Absolute Radar Positioning. ENC 2014.
5. FRP (2012). US Federal Radio-navigation Plan 2012.
6. NSL (2013). Arctic Region GNSS Performance Analysis. Unpublished Report for the GLA.
7. HF-Radar Network (Canada) – http://cordc.ucsd.edu/projects/mapping
8. The new standard in surveillance – [www.kelvinhughes.com/upload/pdf/brochures/vts.pdf](http://www.kelvinhughes.com/upload/pdf/brochures/vts.pdf)

ANNEX

**6 EXAMPLES**

**T**he following tables show assessment results for systems already deployed, near to deployment, or for which technical performance has been demonstrated. It should be noted that the figures used in the

**GLONASS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 6 m 95% | 99% | broadcast by MSI  or RAIM | N/A | 1-0.05 sec | Vulnerable to interference |
| Harbours, harbour approaches, coastal waters | 6 m 95% | 99% | broadcast by MSI (>10s)  or RAIM | ? | 1-0.05 sec | Vulnerable to interference |

Table 4. GLONASS. Source: Russian Federal Space Agency, IAC website

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

**GPS/GLONASS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 2 m 95% | ̴ 100 % | broadcast by MSI  or RAIM | N/A | 1-0.05 sec | Vulnerable to interference |
| Harbours, harbour approaches, coastal waters | 2 m 95% | ̴ 100 % | broadcast by MSI (>10s)  or RAIM | 99.99975% in15 mins | 1-0.05 sec | Vulnerable to interference |

Table 5. GPS/GLONASS. Source: NSL (2013)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

**GPS/WAAS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 9 m 95% | 99 % | broadcast within 6s | N/A | 1-0.05 sec | Vulnerable to interference |
| Harbours, harbour approaches, coastal waters | 2 m 95% | 99 % | broadcast within 6s | 99.99975% in15 mins | 1-0.05 sec | Vulnerable to interference  No polar coverage |

Table 6. GPS/WAAS. Source: FRP 2012

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

**GPS/DGPS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 9 m 95% | 99 % | broadcast within 6s | ̴N/A | 1-0.05 sec | Vulnerable to interference |
| Harbours, harbour approaches, coastal waters | 1-2 m 95% | 99 % | broadcast within 6s | 99.9875% | 1-0.05 sec | Vulnerable to interference |

Table 7. GPS/DGPS. Source: FRP 2012

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

**Multi-GNSS/eLoran**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 8 m 95% | ̴100 % | broadcast within 10s | N/A | 1-0.05 sec |  |
| Harbours, harbour approaches, coastal waters | 8 m 95% | ̴100 % | broadcast within 10s | 99.9875% | 1-0.05 sec | Within coverage of DLoran Ref.Station |

Table 9. Multi-GNSS/eLoran. Source: Williams et al (2013)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |

**6.8 GPS/radar**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | Accuracy | Availability | Integrity | Continuity | Update | Limitations |
| Ocean waters | 9 m 95% | 99 % | broadcast by MSI  or RAIM | N/A | 1-0.05 sec | Vulnerable to interference |
| Harbours, harbour approaches, coastal waters | 7 m 95% | 99 % | broadcast by MSI (>10s)  or RAIM | 99.9875% | 1-0.05 sec | Range limited to 10 M from coast |

Table 10. GPS/radar. Source: Ward et al (2014)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| coverage | Common failure modes | Cross check ability | Interference | Operational Status |
|  |  |  |  |  |