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MarRINav

MARITIME RESILIENCE AND INTEGRITY OF NAVIGATION

Abstract

25th March 2020

MarRINav is a project delivered on behalf of the European Space Agency

MarRINav – Maritime Resilience and Integrity in Navigation

Abstract

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Glossary

CBA	Cost Benefit Analysis
CNI	Critical National Infrastructure
EEZ	Exclusive Economic Zone
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
GLA	General Lighthouse Authorities of the UK and Ireland
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LEO	Low-Earth Orbit
M-RAIM	Maritime Receiver Autonomous Integrity Monitoring
PNT	Position, Navigation, and Timing
RAIM	Receiver Autonomous Integrity Monitoring
RIMS	Reference and Integrity Monitoring Stations
R-Mode	Ranging Mode
SBAS	Space Based Augmentation Systems
STL	Satelles Satellite Time and Location
TSS	Traffic Separation Scheme

1 The need for robust maritime navigation

Shipping is essential to the UK economy, as 95% of all imports and exports are transported by sea. Around 500 million tonnes of cargo are handled by major UK ports each year. Growth in the maritime sector has been driving change in navigation requirements. The number of vessels in the world fleet increased to around 90,000 in 2018. Ship size has increased, on average by 20% overall since 2011. The size of larger ships has increased faster than this: 30% increase for tankers and 32% increase for container ships. This increase in ship size, together with a larger global fleet, is predicted to enable a doubling of seaborne trade by 2030. Traffic complexity and density is increasing in the waters around the British Isles. Already complex and crossing traffic patterns are constrained by the rapid increase in non-navigation marine users competing for sea space, such as offshore renewable energy installations. The safety, efficiency and environmental protection necessary for shipping and port operations leads to the need for increased management of sea traffic and the growing importance of resilience and integrity for positioning, navigation & timing (PNT).

THV *Galatea*

GPS has become the primary marine aid-to-navigation and source of PNT information. Yet, all GNSS are vulnerable to natural interference, deliberate and accidental jamming and spoofing. Trials with the Trinity House Vessel 'Galatea' in the North Sea demonstrated that degraded GPS produces hazardously misleading information and erroneous vessel positions without an alarm being raised. As ships' systems become increasingly digital, with the introduction of a wide range of supporting e-Navigation services and the emergence of autonomous vessels, the PNT accuracy, integrity, continuity and availability becomes ever-more critical.

2 'MarRINav' project objective and approach

The 'MarRINav' (Maritime Resilience and Integrity of Navigation) project, funded by the European Space Agency (ESA), developed the concept of a UK maritime critical national infrastructure (CNI) to provide resilient high-integrity PNT for ships and ports. The project identified candidate technologies, space-based and terrestrial, and their integration into a system-of-systems for operations across the sea/land logistics chain. The MarRINav solution covers the Exclusive Economic Zones (EEZs) of the UK and Ireland, focusing on navigationally critical areas including the approaches to the UK's top 10 ports. The accuracy requirement is 10m (95%) for ships approaching port, with an overall backup accuracy of 20m (95%) elsewhere. The architecture for PNT resilience as much as possible uses terrestrial elements located on UK sovereign territory, under national control.

MarRINav has considered future integrity as primarily based on Satellite-Based Augmentation Systems (SBAS). This implies use of the European Geostationary Navigation Overlay System (EGNOS), mitigating the local impacts of radio noise and multipath by Maritime Receiver Autonomous Integrity Monitoring (M-RAIM).

3 'MarRINav' findings on integrity of Navigation

The accuracy and continuity of current EGNOS V2 capability was investigated for the western extremities of the UK and Irish EEZs. These sea areas are in the outermost expected coverage of the EGNOS service area to understand the western-most limits of service coverage. The analysis was performed using an EGNOS model calibrated for maritime service and found two mechanisms that affect performance in this 'edge of coverage' area, both of which may merit further investigation:

- EGNOS's ground reference stations (RIMS) must be located on land. As the UK and Ireland are at the North-West edge of Europe, this may constrain EGNOS's capability to provide augmentation coverage at the edges of the EEZs. If this were to occur significantly in practice, improvements may be needed, with the possible addition of extra RIMS, for example in the west of Ireland.

- Continuity performance was observed to be sensitive to the elevation mask angle set in the ship's receiver. A trade-off is necessary between improved satellite geometry and increased measurement errors, arising from variations in the elevation mask. It is important that the appropriate mask angles are determined and specified during the development of the IEC test specification for type approval of receivers.

MarRINav made a number of recommendations for potential changes for the future EGNOS V3 maritime service. EGNOS V3 as designed for aviation is not optimised to provide the information needed to satisfy user-level maritime requirements. Position error overbounds are set at inflated (conservative) levels for aviation, whereas maritime integrity may be better accomplished using best-estimate ("fault free") error models. It is necessary to determine a nominal vessel multi-path model, and the associated probability with which instantaneous measurements exceed this model (fault probability). This issue could be addressed by changing the system requirements for the data parameters provided by EGNOS (and other SBAS around the world), or even by considering a new and separate maritime specific SBAS message.

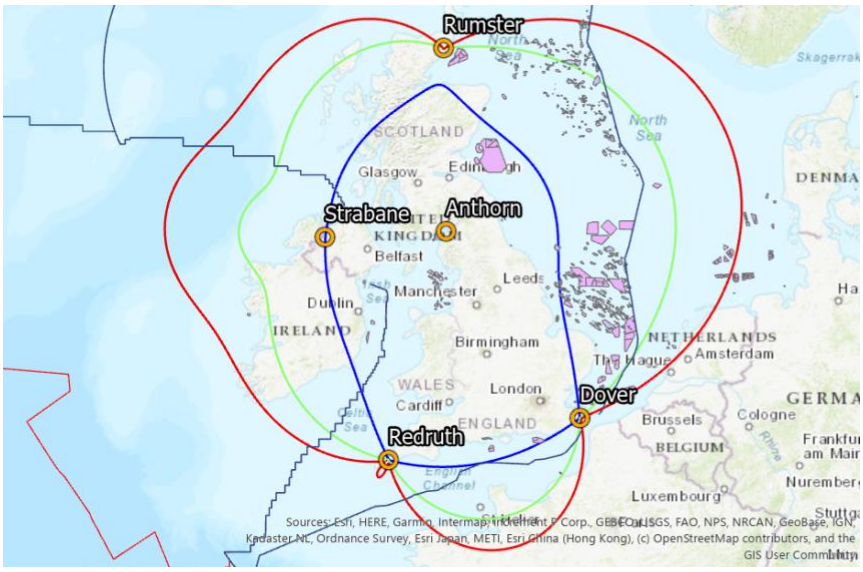
MarRINav also found that an innovative Maritime RAIM (M-RAIM) is a method that shows considerable promise as a candidate form of RAIM for inclusion in the maritime receiver. It is recommended that M-RAIM should be researched further and evaluated for implementation in future maritime receivers when used either in combination with SBAS (e.g. EGNOS V3) or standalone (for marine locations outside SBAS coverage).

4 'MarRINav' conceptual architecture solution

Candidate technologies have been described that could contribute to a conceptual PNT architecture of the maritime Critical National Infrastructure for the UK, in the development of a hybrid system-of-systems, including:

- **E**nhanced **Lo**ng **Ra**nge **N**avigation - eLoran
- Ranging mode of the **V**HF **D**ata **E**xchange **S**ystem - VDES R-Mode
- Radar Absolute Positioning
- LEO **S**atellite **T**iming and **L**ocation (STL), subject to performance confirmation
- LOCATA at ports
- Onboard systems, to integrate traditional and/or inertial Dead Reckoning.

The hybrid system-of-systems PNT solution adopts the principle of primarily using the wide area eLoran system for maximum overall geographic coverage, then supplementing this with regional VDES R-Mode and/or radar absolute positioning to fill capability gaps in the wide area coverage. Six eLoran transmitters are proposed to comprise a UK-only baseline eLoran system.



Accuracy coverage contours of UK based eLoran. Blue = 10 m, Green = 20 m, Red = 30 m.

The UK-only eLoran coverage provides better than 10m (95%) accuracy at 9 out of the 10 largest UK ports and many coastal areas achieve better than 20m (95%), as shown in the figure above. However, the port and straits of Dover, together with the north-eastern approaches to the Channel, are less adequately covered. Analysis of the potential deployment of UK-only VDES R-Mode stations alone has found that UK-only R-Mode is insufficient to fill the gap in positioning capability. However, it would be feasible and of mutual benefit in this high risk area for the UK to cooperate and synchronise with VDES R-Mode transmissions from France, deploying VDES R-Mode on both sides of the Channel. The inclusion of just three VDES R-Mode stations in France, along with the UK VDES R-Mode baseline, was predicted to provide satisfactory positioning coverage at the 10 metres (95%) level for the whole of the Dover Straits and the Port of Dover. The Traffic Separation Scheme (TSS) and its approaches to the north-east of Dover, arguably one of the highest risk maritime areas in the world, could be provided with 20m (95%) level position accuracy by the hybrid solution of closely coupled UK eLoran with VDES R-Mode (including three French VDES R Mode stations).

5 Cost benefit analysis (CBA)

The CBA considered the central economic case of maritime transportation and assumed that one five-day outage of GNSS will take place within the next 10 years. The analysis focused on a scenario with container ships only. The benefits are the loss avoided due to a GPS outage, whilst the costs are those of implementing, operating and maintaining the non-GNSS system-of-systems architecture. Without the MarRINav solution, the total economic loss is **£601m,** whereas with the MarRINav system-of-systems, the total loss is reduced to **£180m**. The total economic value saved is **£421m.** As shown in the table, the net present value of the MarRINav system-of-systems is positive and equal to **£221m**. This is equivalent to a benefit-cost-ratio of **2.2**. Under our assumptions and for **5,200 container ships and 10 major ports**, these results indicate that the investment in a resilient solution is highly beneficial to the wider society.

Benefits and cost	Value (£m)
Benefits (avoided loss)	**421**
Loss without MarRINav	601
Loss with MarRINav	180
Costs	**200**
Costs of ashore infrastructures	80
Costs to ship-owners	120
Net Present Value	**+221**
Benefit-cost ratio	**2.2**

6 Conclusion and recommendations

Further research in future phases of the MarRINav project would prove the concept of the PNT solution architecture and the effectiveness of M-RAIM in conjunction with EGNOS v3. An Outline Development Plan has indicated how to implement a test-bed demonstrator to prove the concept of the hybrid system-of-systems solution at a local scale for a variety of users (not confined to maritime). Outputs from the test-bed demonstrator would support design and implementation of a resilient PNT architecture for CNI at UK national scale. The plan identifies proof-of-concept activities, based on the implementation of a **physical** system-of-systems into a **test-bed** demonstrator. This would be supported by a modelling & **simulation test-bed** to provide insights for its physical realisation. The philosophy of the test-bed development process is to build incremental development of each system's technological maturity.

With 95% of all UK imports arriving by sea, it is hard to overstate the importance of maritime shipping's societal impact and the benefits of the MarRINav solution to the UK national interests. Movement of goods in an efficient manner is vital to the economic and social welfare of those living in the UK.

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