Maritime Resilience and Integrity of Navigation

Mike Fairbanks and Bob Cockshott explain the need for a resilient high-integrity PNT solution for maritime navigation in the UK, and outline what is being done to achieve this.

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Shipping is essential to the UK economy, as 95% of all imports and exports are transported by sea. Around 470 million tonnes of cargo were handled by major UK ports in 2017.

The number of vessels in the world fleet has increased by 13% to around 90 000 between 2011 and 2018. The average size of these vessels has increased by 20% overall. The size of larger ships has increased faster than this: 30% increase for tankers and 32% increase for container ships. The largest lift-on lift-off (lo-lo) vessels (such as OOCL Hong Kong) are now over 400 metres in length and can carry over 21 000 twenty foot equivalent (TEU) containers.

The Straits of Dover and its approaches, with the combination of traffic to UK and major European ports, is one of the busiest in the world. Already complex and crossing traffic patterns are also constrained by the rapid increase in non-navigation marine users competing for sea space, such as offshore renewable energy installations. Figure 1 (to the right) illustrates the compression of vessel routes within traffic separation schemes and the close adherence of ships' navigation to predefined voyage plans, which may be determined for the lowest cost of operation.

From Marine Accident Investigation Branch (MAIB) statistics, the total loss rate per year for vessels ≥100 gross tonnage (gt) in UK jurisdiction is decreasing but collisions appear to

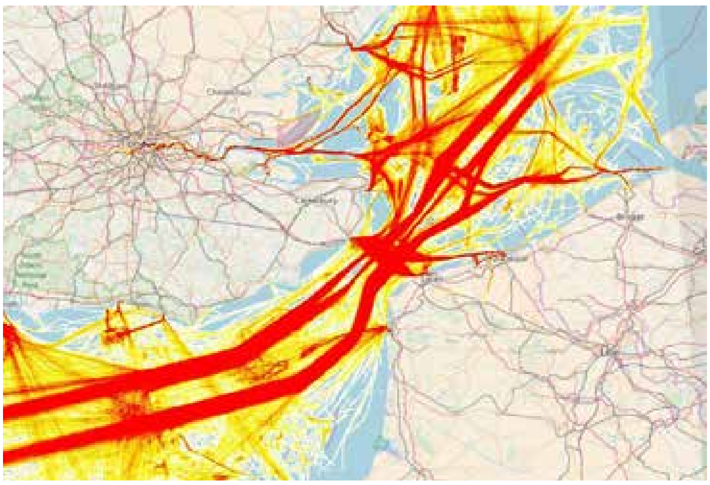

Figure 1: Depiction of vessel routes around the Straits of Dover and its approaches

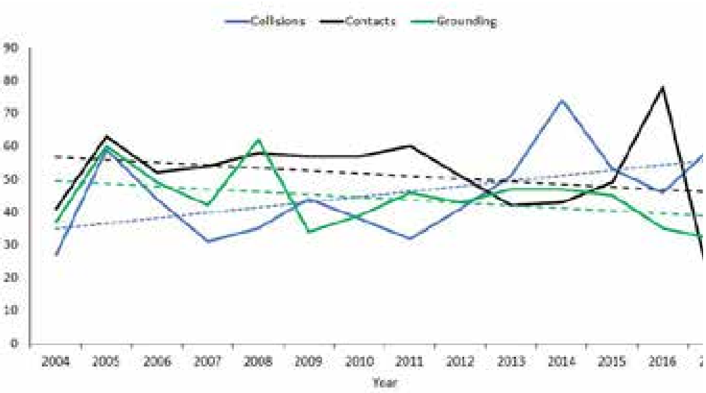

Figure 2: Breakdown of navigation-related incidents through time between 2004 and 2017

be increasing as shown in the figure for navigation-related incidents (Figure 2, above). Human error remains the biggest factor in accidents.

GPS has become the primary marine aid-to-navigation, with physical aids such as lighthouses and buoys remaining important but secondary. Yet, GPS and all other Global Navigation Satellite Systems (GNSS) are vulnerable to natural interference, deliberate jamming and spoofing. Trials with THV Galatea in the North Sea show that GPS can degrade and provide hazardly misleading information without an alarm being raised. The ensuing small but significant

THV Galatea

errors in navigation are not easily perceived by the mariner. In situations where GPS becomes unavailable, many of the ship's systems will alarm, increasing stress and workload for the bridge crew. This raises the risk of human error, even for the most well trained mariners, when facing such challenging conditions in complex sea spaces around the UK.

At the macroeconomic level, the recent London Economics Report for UK government estimated that a 5 day outage of GPS would lead to £1bn loss to the UK economy from the shipping and ports sector alone. There is a pressing societal and economic need for resilient and high-integrity Position Navigation and Timing (PNT) information to be provided to mariners. This must meet international performance requirements for accuracy, integrity, continuity and availability, even during periods when GNSS is degraded or denied. As ships' systems become increasingly digital, and with the introduction of e-Navigation services being dependent on the trustworthiness and continuity of PNT data, the case for GNSS augmentation to provide integrity and for backup systems to provide resilience is compelling. The need is recognised by the International Maritime Organization, which has introduced (in 2015) a performance standard for a maritime multi-constellation multi-system receiver (MSR). The need for resilient PNT is also acknowledged by the European Commission in its European Radio Navigation Plan (2018) and by the UK in the Blackett Report (2018).

The 'MarRINav' (Maritime Resilience and Integrity of Navigation) project idea was instigated by the General Lighthouse Authorities (GLA) to research and develop a UK maritime resilient high-integrity PNT solution. The project's approach combines GNSS, including space based augmentation systems (SBAS), with terrestrial systems and radio aids-to-navigation, in line with the concept embodied within the existing MSR performance standard. The MarRINav project is funded by the European Space Agency and led by NLA International with contributory expertise drawn from UK academia and industry.

MarRINav will develop a conceptual architecture for the system-of-systems: core GNSS, augmentation and backups – needed to guarantee resilient PNT on ships within UK territorial waters. It will consider the mix of different technologies and the geographic distribution of RF transmitters, signal augmentation and monitoring within the UK that could form a practical hybrid solution. Maritime transmissions will need to be locked to precise time (UTC from a robust UK source) so that individual pseudorange measurements from GNSS sateliites (when available) and backup transmitters can be integrated in the ship's receiver (MSR) by a method analagous to the 'all-in-view' capability of GPS receivers. MarRINav will predict future service volume coverage for individual technologies and hybrid solutions, resulting from analysis of transmitter locations, radiated powers and received signal geometries.

Options for GNSS backup systems for UK maritime resilient PNT are more limited than for the land domain, as radio navigation signals need relatively long range and diverse geometry (for positioning capability from trilateration) across waters up to the 200 mile limit of the UK exclusive economic zone (EEZ). The London Economics report indicated the potential of eLoran and STL (using Iridium LEO satellites), with local beacon-based Locata infrastructure at ports. The MarRINav project is exploring all of these and more: absolute positioning from ship's radar image processing, and 'R-Mode', the addition of precise Timing modulation to future maritime VHF Data Exchange System (VDES) transmissions (which include AIS) or to Medium

Frequency transmissions of marine Differential GPS (DGPS) radio beacons. The graphic below illustrates a conceptual architecture considering all of these systems in the context of the future e-Navigation environment.

In Europe, the EC is planning a maritime service based on the existing evolution of the European Geostationary Navigation Overlay Service (EGNOS V2), with possible introduction by the end of 2021. The proposed service would guarantee the provision of warnings to mariners of GPS system faults, protecting the vessel against errors in position caused by malfunction of GPS satellites or ground processing. Vessels regulated by International Maritime Organisation (IMO) Safety of Life (SOLAS) resolutions would need to equip with new type-approved receivers to benefit from this service. Existing maritime DGPS beacons already provide suitably equipped vessels in coverage of a beacon with this 'position integrity at system level'. The EGNOS V2 service would cover a much wider geographical region. Questions remain about the relative and combined benefits of the two systems. For example, in the most northerly and westerly waters of the UK and Ireland, there are indications that EGNOS V2 performance may nearly but not fully meet IMO requirements. The MarRINav study will compare maritime EGNOS V2 and DGPS beacons for a variety of maritime locations and a spread of GPS environmental conditions.

However, simply delivering 'integrity at system level', regardless of how the integrity message is derived and delivered, fails to take into account potential errors caused by disturbances to the navigation satellite signals local to the vessel. This raises the fundamental question of whether current solutions are suitable for maritime service. 'Integrity at user level', taking into account local effects, is needed.

Perhaps surprisingly the maritime environment is more challenging than that for aviation. Accuracy and continuity requirements for maritime port and harbour approach are higher than those for aircraft approaches using GNSS. Trials show that maritime receivers experience more satellite signal blocking and reflections, and more radio interference than aircraft receivers. Hence, building on recent EU studies of the maritime potential of SBAS (EGNOS V3), MarRINav is investigating methods to guarantee maritime 'integrity at user level' with M-RAIM (Maritime Receiver Autonomous Integrity Monitoring), a method adapted for maritime by GLA from aviation's Advanced RAIM (ARAIM).

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Graphic illustrating a conceptual architecture of the future maritime navigation environment