# The Deployment of eLoran in the UK

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## BIOGRAPHIES

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David Last is a Professor Emeritus in the University of Wales. He is the Immediate Past-President of the Royal Institute of Navigation and a former President of the International Loran Association. David is a Chartered Engineer who has published many research and policy papers on navigation systems and acts as a Consultant on radio-navigation and communications to companies and to governmental and international organisations. He is an instrument-rated aircraft pilot and user of terrestrial and satellite navigation systems.

Dr. Nick Ward is Research Director of the General Lighthouse Authorities of the UK and Ireland, with responsibility for strategy & planning of research & development. His work involves radio-navigation and communications and he has been closely involved in the development and international standardisation of radar beacons, Differential GNSS and the Automatic Identification System (AIS) and now with e-Navigation. He has also been engaged with the development, specification and deployment of Loran systems for the past 25 years. He is currently vice chairman of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) e-Navigation committee, is a Chartered Engineer and a Fellow of the Royal Institute of Navigation.

## ABSTRACT

The transition from traditional maritime navigation to e-Navigation, is being led by the International Maritime Organisation. Already on many vessels, officers rely almost entirely on satellite navigation. e-Navigation will increase their dependence on electronic systems. The General Lighthouse Authorities (GLAs) believe that if e-Navigation is to enhance, and not reduce, safety it will be essential to have two independent, robust sources of position aboard. To provide this, the UK now has the first prototype eLoran system working alongside GPS. Operating 24/7 since May 2010, it demonstrates the concept of eLoran using signals from existing Loran-C stations in Norway, the Faroe Islands, Germany and France, plus the UK's new station at Anthorn. Using the eLoran differential mode, it can already deliver a high-precision service in ports where 10-20 metre accuracy is needed; yet the full availability and accuracy benefits of eLoran are still to come.

This prototype service now covers the Port of Dover and the UK section of the Dover Strait, the world's busiest maritime chokepoint and an area highly vulnerable to GPS jamming from land. A cross-Channel ferry will demonstrate the service and collect long-term performance data.

This paper will show how to bring on air a high-performance differential eLoran service like this. First, the effects of land masses are mapped across the proposed service area; an Additional Secondary Factor (ASF) map is generated for each station. This is a once-and–for–all task, because the land does not move. Then, in real time, a reference station close to the harbour measures any small temporal changes in the signals' arrival times due to transmitter variations and weather effects. Corrections for these errors, broadcast from a Loran station, let users' receivers hold the positions steady.

This leading, prototype eLoran system provides two further important services: UTC time and frequency; and secure data communications. Receivers now available use eLoran to continue Stratum 1 timing for telecommunications services when GNSS is lost. In addition, government users can input short messages into the eLoran data stream, so protecting certain national critical data from jamming. Power-efficient receivers for data reception have been developed. Next, eLoran will be demonstrated as a back-up to GPS in tracking road vehicles carrying cargoes of high value or high security.

## I INTRODUCTION

The International Maritime Organisation is developing a strategic vision for e-navigation, integrating existing and new navigational tools in an all-embracing system, contributing to enhanced navigational safety and environmental protection, while reducing the burden on the navigator. One of IMOs requirements for e-Navigation is that it should be resilient - robust, reliable and dependable. Requirements for redundancy, particularly in relation to position fixing systems should be considered.

## II DEPENDENCE ON GNSS

At present the primary electronic position input for maritime navigation is GPS and GPS is known to be vulnerable to intentional and unintentional interference.

Even so, it is everywhere aboard ship – it's output is displayed on the ECDIS, it is transmitted to other vessels using AIS, it is used to calibrate the gyro compass, it's in the RADAR, to stabilise the output, the digital selective calling system uses it to provide position for search and rescue, GPS provides the position input to the vessel data recorder used for accident investigation, dynamic positioning systems and surveying equipment use it, the ship's communications and entertainment systems use it for aiming the satellite dish and it even synchronises the ship's clocks!

GPS is also used in the provision of conventional Aids to Navigation (AtoN), for deploying buoys and lights, in AIS transponders, for position monitoring of AtoN and its precise timing capabilities are used to synchronise the lights along an approach channel – improving conspicuity.

## III VULNERABILITY

So it can be seen that maritime navigation is heavily dependent on GPS now and this produces a single point of failure – the very opposite of resilience. This situation will improve a little with the introduction of other GNSS, although the rate of replacement of equipment in the maritime industry is very slow. Even with multiple GNSS the vulnerability will remain. The systems themselves are very reliable, the causes of failure are usually onboard – power supplies, equipment breakdown or interference. The equipment problems can be mitigated by redundancy, but interference, whether accidental or deliberate, is likely to affect all equipment. All GNSS share the same characteristics: extremely low signal level, frequencies in the 1.2-1.6 GHz range and line of sight signals. The only way to mitigate this vulnerability is to provide a dissimilar system.

## IV BUSINESS CASE

In 2010 the General Lighthouse Authorities of the UK & Ireland analysed various options for providing resilient PNT. The results were presented in the form of a business case that followed UK Treasury rules.

The outcome was clear – eLoran was the only option available in the timescale required for e-Navigation that could provide real resilience. eLoran is a high power, low frequency terrestrial system, so it is truly complementary to GNSS. The business case showed that, if it was implemented, it would allow rationalisation of the physical AtoN infrastructure, removal of some lights and other physical aids, that would on balance, actually reduce overall costs. None of the other options would lead to this result and they might not be available in the timescale required.

## V THE ELORAN CORE SERVICE

eLoran is derived from the old Loran-C system, in fact the core signal of eLoran is similar to that of Loran-C. However, timing tolerances are much tighter, a data channel is incorporated and accuracy and integrity are greatly enhanced.

eLoran transmitters are synchronised directly to UTC – their times of transmission can be predicted, so the signal is a stratum 1 frequency source, suitable for steering the clocks of telecom networks.

As a result of the UTC synchronisation, the old hyperbolic navigation concept oLoran-C is no longer needed.and all signals in-view can be used. Modern receivers are small, use off-the-shelf, high speed processors, the receiver being written in software. The position solution is computed in the same way as a GPS receiver, using ranges to transmitters on the ground instead of to satellites.

The data channel mentioned above is provided by modulating some of the Loran pulses in each group, so that integrity alerts, and application system specific data, like UTC time, and differential corrections can be carried on the Loran signal. Some options for data channel technology are still evolving with 1500 bits per second demonstrated, and 3000bps possible – quite a high rate for a 100 kHz signal.

## VI APPLICATION SERVICES

In order to apply eLoran to a port approach, for example, it is first necessary to survey the effects of land masses in the area of coverage; these 'Additional Secondary Factors' (ASF) are surveyed for all the stations across the proposed service area. The ASF values provide adjustments for propagation delay due to land, taking account of the difference between the time taken for the groundwave signal to travel over the surface of the earth, compared with the time taken to travel over sea-water. This ASF survey is a once-and–for–all task.

Then, in real time, using a differential–Loran reference station, close to the harbour approach, the very small temporal changes in the signals' arrival times due to transmitter variations, weather effects and changing ASF are measured. The reference station sends corrections for the variations over the Internet to a Loran station which broadcasts them to the user's receiver on the Loran Data Channel. With good signal to noise ratio and transmitter geometry the accuracy achieved is 10m or better.

## VII ASF MEASUREMENTS

ASFs can be measured using a combination of commercial hardware and bespoke software. This takes raw ASF data and processes it in real-time aboard the survey vessel, or post-mission, to get the best performance out of the data.

The error bounds of the ASF measurements can also be estimated, for publication alongside the ASF database and use in an integrity equation to calculate Horizontal Protection Levels. Using knowledge of the expected spatial variations of the ASFs, it was possible to limit the survey tracks to the outer edges of the coverage area and fill in the middle by interpolating the measured data, because in this region the ASFs are likely to vary smoothly. Once the data has been collected and processed it can be stored within the mariner's receiver. Interpolation fills in the data in the middle and extrapolation extends the data to regions outside the tracks.

The interpolation works very well, but the extrapolation is inherently more error prone, because there is less information available to 'bound' the resulting values. When the data is published, the mariner needs to be advised on the measurement error associated with each region of the map.  So anywhere within the survey area, measurement error can be predicted with some certainty, but anywhere outside it the error could be higher and less certain.

Therefore it is proposed that, as well as an ASF map, an ASF quality map should be published. This can be in the same format as the ASF data, but it contains an error bound on the ASF measurement. This means twice as much storage for each map, but the cost of memory is not a constraint.

## VIII ELORAN PROTOTYPE ON THE AIR

A prototype differential-Loran Reference Station has been in continuous operation for a number of years, providing port approach level eLoran (10m level accuracy) along the Harwich and Felixstowe approach channel.

This prototype eLoran system works alongside GPS. It's been there 24 hours a day since May 2010. It is referred to as "prototype" since it demonstrates the concept of eLoran, using signals from existing Loran-C stations in Norway, the Faroe Islands, Germany and France plus the UK's station at Anthorn.

It can deliver a high-precision service using differential-Loran in ports where 10-20 metre accuracy is needed. However, the full availability and accuracy benefits of eLoran have still to be realised and similar services are now being implemented in other parts of the GLA service areas.

## IX ELORAN IMPLEMENTATION

The plan is to implement eLoran in two phases. An Initial Operational Capability (IOC) service will be installed by the end of 2014, with a Full Operational Capability (FOC) service covering all major ports in the UK and Ireland, plus Traffic Separation Schemes installed by 2019, in time for e-Navigation.

IOC involves upgrading the installation at Harwich/Felixstowe and installations at the other 6 busiest ports on the UK East coast; Aberdeen, Grangemouth, Middlesbrough, Immingham, Tilbury and Dover.

The IOC implementation is starting in the Port of Dover, a major port on the southeast coast of the UK. The Dover Strait is one of the busiest seaways in the world – some 500 plus vessels per day travel through here on their way to or from the North Sea Region.

### A Dover

A differential-Loran Reference Station has been installed in the Port of Dover Operations Control building and the Dover ASF survey has been completed. Planning of the ASF survey started with a traffic analysis, using AIS data, which showed the major traffic concentration areas. The next step was to prioritise the regions within that zone. For this early implementation the main interest is in the ferries crossing the zone and the cargo vessels and tankers travelling up and down the main parts of the channel. So the survey covered the ferry routes, the harbour approach itself and the traffic separation scheme.

**1) Validation**

Once ASFs had been measured and the reference station installed at Dover, it was necessary to test the performance. This was done through a validation run of the vessel through the area. The vessel travelled through an area of extrapolated and interpolated ASF data. The eLoran position was compared to DGPS as the ground truth position and a scatter plot produced. A Cumulative Distribution Function showed 12.5m (95%) as the positioning accuracy along that particular track.

**2) Ship Installation**

With the agreement of P&O Ferries in the UK, an eLoran receiver has been installed aboard their £157M vessel, "The Spirit of Britain" - one of the largest passenger ships to operate on the Dover to Calais route. Data will be collected and feedback obtained on the performance of the service over the coming years.

### B Thames Estuary

After Dover the next area planned for the GLAs eLoran Initial Operational Capability is the Thames Estuary – the ASFs have been mapped and in the approaches to the Thames Estuary, roughly 8m (95%) accuracy can be achieved, in line with expectations from coverage prediction. A temporary reference station was installed for the ASF survey and the final operational reference station will be located in a building owned by the local port authority.

### C Humber

In the approaches to the Humber, the ASF survey has been completed and validated. Again 8m (95%) accuracy can be achieved using a temporary reference station and a convenient location has been found for the operational station at a radar tower owned by the local port authority.

### D Completion of Coverage

These local surveys for port approaches leave gaps in coastal coverage. In the future it is planned to fill in these gaps along the coast between the ports, for coastal phase navigation. This will be done using ships of convenience, including GLA vessels and possibly "crowd sourcing" of ASF data.

## X CROSS-SECTOR APPLICATION

An international asset like eLoran should be of benefit to more than just the maritime sector, and there is an advantage in sharing running costs of the service between the mariner and other potential users. For this reason the cross sector use of eLoran is being promoted. The transmitter at Anthorn can already provide 50ns timing and Stratum 1 frequency, and it has not yet been fully upgraded to a final eLoran specification. The GLA have been involved in projects like GAARDIAN and SENTINEL looking at GNSS and eLoran service quality for such applications as timing and GNSS interference detection on land. A client is using the transmitter at Anthorn to transmit secure scheduled messages over the Loran Data Channel - not using the signal for position, navigation and timing, but for data.

Several parties are interested in developing an eLoran based land mobile demonstrator – using eLoran for land vehicle tracking.

The GLA are leading the European, INTERREG funded ACCSEAS project, which also has trans-modal implications. The project is establishing an e-navigation test-bed in the North Sea Region, with a resilient PNT stream of work. This is covered in more detail in another paper at this conference.

## XI CONCLUSIONS

- Maritime navigation is heavily dependent on GPS at present.
- e-Navigation is the future digital concept for the maritime sector, but must be supported by resilient systems
- GNSS has vulnerabilities and a complementary system is needed for resiliency. eLoran is the only proven system that can provide that resiliency. A business case has shown that eLoran could produce substantial cost savings through rationalisation of physical infrastructure.
- The GLA have demonstrated the perfromance of eLoran in UK waters and have begun to implement it on the East coast with Initial Operational Capability.
- eLoran has applications across many sectors, in support of critical infrastructure and the cost does not need to fall on the maritime sector alone.