Research & Radionavigation
General Lighthouse Authorities
United Kingdom and Ireland

The Case for eLORAN

Research and Radionavigation
General Lighthouse Authorities of the United Kingdom and Ireland
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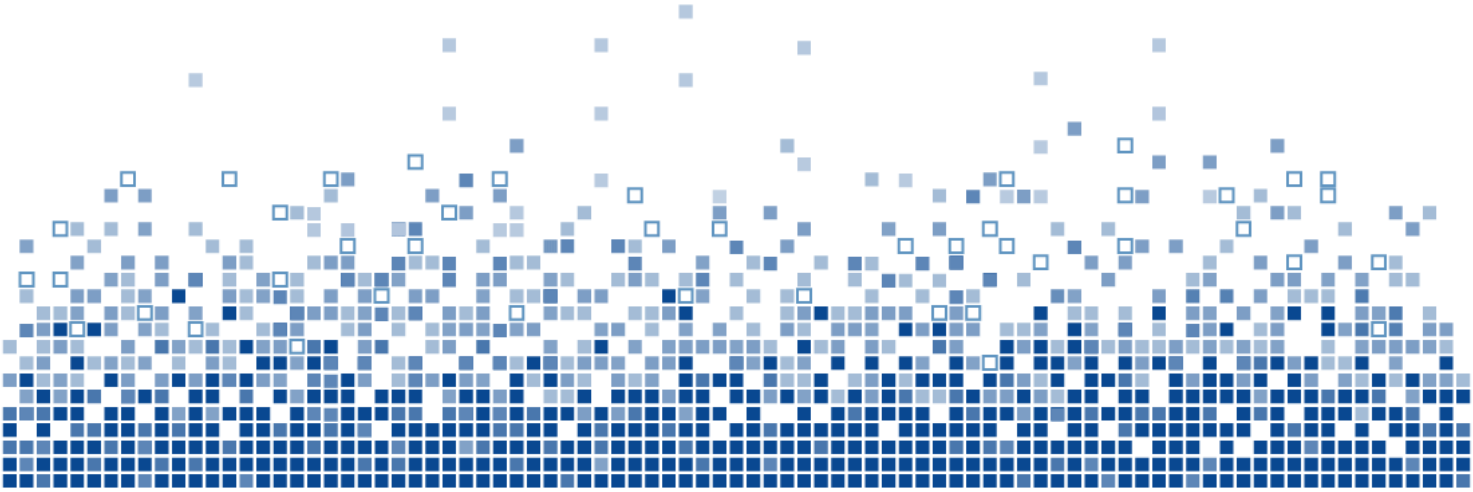

Executive Summary

The General Lighthouse Authorities (GLAs) of the United Kingdom and Ireland are Trinity House, the Northern Lighthouse Board and the Commissioners of Irish Lights. Together, they have the statutory responsibility for the provision of marine aids to navigation (AtoNs) around the British Isles. The GLAs operate in a "user pays" cost-recovery environment based on "Light Dues" charged on various classes of shipping calling at ports in the UK and Ireland. Their joint mission is the delivery of a reliable, efficient and cost effective AtoN service for the benefit and safety of all mariners.

The world's shipping industry is experiencing a period of strong growth with seaborne trade at a record level of 6.76 billion tonnes in 2004 and set to increase (forecast at 4% per annum over the period 2000-2010). Ships are getting larger and faster, sea-lanes are more crowded and crews are less experienced in this environment. The English Channel is the world's busiest shipping area, with a ship passing through the Dover Straits on average every three minutes. The GLAs have an essential role to play here and elsewhere around the British Isles.

The UK Government has championed the new e-Navigation concept based on global navigation satellite systems (GNSS) that is intended to set international standards to make safe navigation easier and cheaper. Physical AtoNs (principally buoys and lights) will always be needed to provide a reversionary capability because of the inevitable vulnerabilities of GNSS. However, reverting from e-Navigation based solely on GNSS to physical AtoNs will become less straightforward over time because mariners will become less familiar with the traditional skills needed to navigate using physical aids. In some cases, safety might actually worsen.

eLoran is needed both to ensure safety in a higher-risk environment and to deliver a radionavigation dividend – cost savings that result from the introduction of radionavigation services and their take-up in the maritime sector. eLoran is a low-frequency, terrestrial navigation system operating at 100 kHz and synchronized to Co-ordinated Universal Time. It is intended to meet the required navigation performance parameters for a range of transport and timing applications including marine general navigation. Initial differential eLoran trials conducted at Harwich in April 2006 and using the GLAs' test transmitter at Rugby have demonstrated horizontal positioning accuracies better than 9m with 95% confidence using modern, miniaturised eLoran receivers. This puts eLoran on the same basis as single frequency GPS or Galileo: each requires differential corrections to guarantee meeting the International Maritime Organisation's future accuracy requirements for port approach and restricted waters.

When the actions to deal with institutional and LORAN station matters set out in this document are undertaken, receiver developers will be stimulated to invest in development and production of integrated GNSS/eLORAN equipment. This will make receivers cheaper and more widely available.

The 'Case for eLoran' shows how the GLAs will develop the UK's lead role in e-Navigation. This work will follow on from the expected adoption in May 2006 by the International Maritime Organisation's Maritime Safety Committee of e-Navigation as a key part of the work programme for its Navigation sub-committee.

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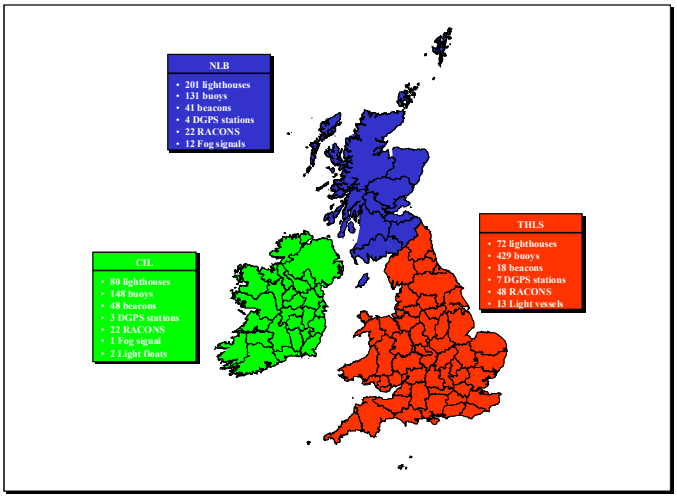
1 Introduction

1.1 The General Lighthouse Authorities

The General Lighthouse Authorities (GLAs) of the United Kingdom (UK) and Ireland are Trinity House (TH), the Northern Lighthouse Board (NLB) and the Commissioners of Irish Lights (CIL). Under acts of Parliament in the UK and Ireland, the GLAs are mandated to assume the obligations of their Governments under the Safety of Life at Sea Convention (SOLAS) for the adequate provision of such aids to navigation (AtoNs) in and around each of their respective areas as the volume of traffic *justifies* and the degree of risk *requires.* Specifically, the UK and Republic of Ireland legislatures have provided that the GLAs shall be responsible for the superintendence and management of all lighthouses, buoys and beacons in their respective geographical areas, subject to certain provisions regarding aids in Local Lighthouse Authority areas. The GLAs' joint mission is the delivery of a reliable, efficient and cost effective AtoN service for the benefit and safety of all mariners.



These mission objectives are achieved through the implementation, operation and maintenance of a mix of different types of aids including radionavigation systems, lighthouses, light vessels, buoys, visual beacons and fog signals, as follows:

	Number of aids provided		
Type of aid	**Trinity House Lighthouse Service**	**Northern Lighthouse Board**	**Commissioners of Irish Lights**
DGPS beacons	7	4	3
Radar beacons	48	22	22
Lighthouses	72	201	80
Light vessels	13	0	0
Light floats	0	0	2
Buoys	429	131	136
Visual beacons	18	41	48
Fog signals	0	12	1
Large automatic navigational buoys	0	0	2

Source: Trinity House

The costs of these AtoNs are met from a common fund known as the General Lighthouse Fund (GLF) whose principal income is light dues charged on various classes of shipping calling at ports in the UK and Ireland. Trinity House collects the light dues on behalf of the GLAs, mainly through ship-broking agents at the ports. The UK Secretary of State for Transport has responsibility for the GLF and sets the level of dues to be charged. The GLAs have delivered significant cost-efficiencies that have reduced the cost of light dues by 50% in real-terms over the last decade.

The GLAs are subject to significant pressures regarding the services they provide including increasing requirements, the universal availability of external, uncontrollable but widely used satellite navigation services, strong downward pressures on costs, and a more litigious environment. The GLAs' response to these pressures is the strategy for the future set out in the document *2020 The Vision*, which promulgates the policy of the UK for the provision of marine aids to navigation.

1.2 The Future of Marine Navigation

Bearing in mind the certain weaknesses of current marine navigation, and in response to emerging challenges, the UK has championed the e-Navigation concept. This is intended to make safe navigation easier and cheaper and to support new applications. It encompasses the cost-effective collection, integration and display of maritime information onboard and ashore by electronic means, so as to enhance berth-to-berth navigation and related services for safety and security at sea, and to protect the marine environment. Within the International Maritime Organisation (IMO), the UK, with the active support of Japan, the Marshall Islands, the Netherlands, Norway, Singapore and the United States of America (USA), has proposed to the Maritime Safety Committee that it should adopt a work programme to achieve the e-Navigation goal. In addition, the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) has chartered a new e-Navigation committee that will replace its Radionavigation (RNAV) and Automatic Identification System (AIS) committees, following the IALA conference in Shanghai in May 2006. This committee will define e-navigation fully and will develop a vision for the integration of current and future technology and information displays to maximize the benefits for all users in the maritime domain. It will also participate fully in the development of the e-navigation environment, and in the development of future electronic systems that will alter the mix of AtoN and maritime information systems.

e-Navigation objectives

- minimise navigational errors, incidents and accidents
- protect people, the marine environment and resources
- improve security
- reduce costs for shipping and coastal states
- deliver benefits for the commercial shipping industry

e-Navigation is expected to be based on a number of structural components:

- accurate, comprehensive and up-to-date electronic navigation charts
- accurate and reliable electronic positioning signals
- information on a vessel's route, bearing, manoeuvring parameters and other status items, in electronic format
- transmission of positional and navigational information from ship-to-shore, shore-to-ship and ship-to-ship, using the AIS
- clear, integrated displays of the above information on board ship and ashore, using electronic chart display and information system (ECDIS)
- information prioritisation and alert capability in risk situations on ship and ashore.

e-Navigation will also provide the one mechanism through which the numbers of expensive physical AtoNs could be further reduced, resulting in substantial cost savings.

Global navigation satellite systems (GNSS) – currently the Global Positioning System (GPS) and GLONASS, plus in the future, a combination of GPS, GLONASS and Galileo – will obviously make up the nucleus of the position and time measurement component of e-Navigation. Physical AtoNs will always be needed to provide a reversionary capability because of the well-known vulnerabilities of GNSS. However, reverting directly from e-Navigation based on sole-means GNSS to physical AtoNs (principally buoys and lights) is likely to become ever less straightforward as time progresses; this is because seafarers will become less familiar with, and less current in, the traditional skills needed to navigate using physical aids. In some cases, reverting to lights and buoys upon a failure of GNSS, might increase the level of risk and reduce the level of safety. That is, the level of safety might actually worsen as a result of the adoption of e-Navigation. A consequence would be the

need to provide additional physical AtoNs and require more restrictive operational procedures, in order to insure against and alleviate potential risks during GNSS outages.

- ✓ **e-Navigation is a potential enabler of new applications to meet emerging and future requirements for marine navigation**
- ✓ **e-Navigation has the potential to deliver direct benefits to users through improved operational capabilities and also to reduce Light Dues if it enables the GLAs to remove physical AtoNs**
- ✓ **the benefits of e-Navigation could be seriously eroded through the measures that would have to be taken to avoid prejudicing safety in the event of failure of a GNSS that was the sole source of input position data**

Logically therefore, a second, complementary and dissimilar, independent radionavigation service that delivers positioning, navigation and timing information, is needed if we are to realise the full benefits of e-Navigation. This system would have to be similar in performance to GNSS in order that any reversion to it upon the loss of GNSS would be transparent to the user (although the user would, of course, be advised that it had occurred). If that condition was met, additional systems and procedures would not be necessary.

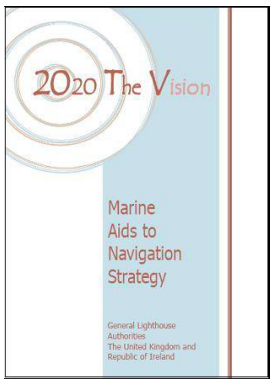
This requirement for a second, independent input into systems that are totally reliant on electronic position fixing is fully consistent with best navigation practice, although specific systems are not specified by the IMO.

At the European level, the recent study to define a European Radionavigation Plan (ERNP) made several recommendations that explicitly identify LORAN as such a system:

> *The EU should work with Member States to investigate the European-wide provision of LORAN-C services in order to secure both transport and wider socio-economic policy benefits delivered by LORAN-C*
>
> *The EU should work with Member States to harmonise LORAN-C standards*
>
> *The EU should work with Member States to support the development of multi-modal receivers to ensure [LORAN-C] service take-up*
>
> *The EU should work with Russian Federation Chayka authorities to understand their plans for the service and the potential for interoperability with LORAN/Eurofix…*

Building on these recommendations to explore the continued provision of LORAN-C, and noting their statutory obligations vis-à-vis the provision of safe and expeditious services, the GLAs set out their position even more explicitly in *2020 The Vision*:

> "*There are concerns about the vulnerability of GNSS in view of the total reliance on the system…*
>
> *…the provision of a terrestrial radionavigation backup…*
>
> *…essential…*
>
> *LORAN-C is the only terrestrial radionavigation backup currently operational that has the potential to fulfil these requirements*"



1.3 The Concept of eLORAN

Notwithstanding the positive references to LORAN made above, the performance limitations of both the transmitters and the receivers in traditional LORAN-C systems have led to serious doubts that they could meet the requirements of some of the more stringent applications in the marine sector, particularly in harbour entrance and approach (HEA). The USA Government funded a study[1], led by the Federal Aviation Administration (FAA), entitled "*LORAN's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications*". The principal conclusion of this study was as follows:

> *"The evaluation shows that the **modernized** LORAN system can satisfy the current NPA[2], HEA[3], and timing/frequency requirements in the conterminous United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the users to retain the benefits they derive from their use of GPS"*

Clearly "modernized" is the key word in this conclusion. The need to modernise has led to the concept of "enhanced LORAN", or eLORAN:

> *"…a low-frequency, terrestrial navigation system operating in the 90- to 110-kHz frequency band and synchronized to coordinated universal time…*
>
> *…a new communication modulation method that enables operations that satisfy the accuracy, availability, integrity, and continuity performance requirements for…*
>
> *… harbor entrance and approaches, as well as the requirements of non-navigation time and frequency applications.*
>
> *changes to the current system include modern solid-state transmitters, a new time and frequency equipment suite, modified monitor and control equipment, and revised operational procedures that new receiver technology can exploit."*

There is not yet a fixed specification for eLORAN, but there is a clear view of the performance standards it needs to achieve in order to satisfy the requirements of the aviation, maritime and timing communities. The following figure sets out (top row) the accuracy, availability, integrity and continuity of traditional LORAN-C systems, in the form of the "current definition of capability" from the US Federal Radionavigation Plan (FRP). It then (second row) identifies the much higher requirements imposed by the target of supporting aviation Non-Precision (instrument) Approaches (NPA), in accordance with Required Navigation Performance standard RNP0.3. Finally (bottom row), it introduces the US Coast Guard's requirements for Harbor Entrance and Approach (HEA). Note that eLORAN has to meet the highest performance requirement across the various modes of transport in respect of each individual parameter. Thus, it must satisfy the most demanding accuracy requirement (the maritime figure) and the most demanding availability, integrity, and continuity figures (from the aviation specification).

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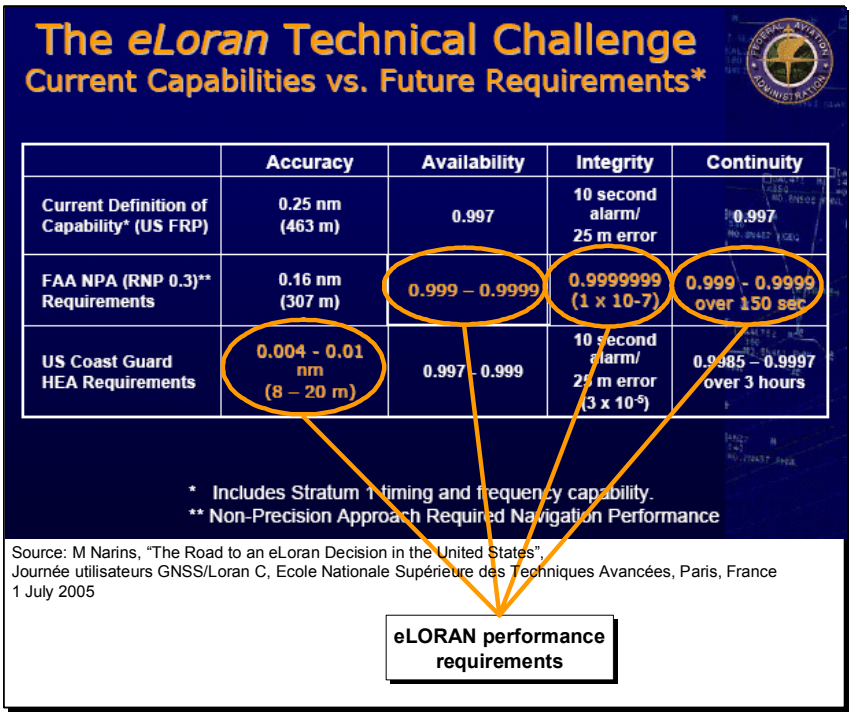
1 *FAA, "LORAN's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications", March 2004,*

2 *NPA – Non-Precision Approach*

3 *HEA – Harbour Entrance Approach*

eLORAN performance



Clearly, this formidable set of requirements exceeds in respect of every parameter the performance standards of traditional LORAN-C. The modernisation of the system that has enabled this higher performance to be achieved is detailed in the set of "eLORAN actions" presented in the tables below. These may be regarded as a checklist of the improvements required to bring the US LORAN-C system up to the new eLORAN standard.

Almost all the upgrades to the transmitter stations set out in this diagram have now been completed, at least throughout the continental US (with Alaska to come), within the context of the LORAN Recapitalization Program funded by Congress. The feasibility of all other changes has been demonstrated both experimentally and theoretically within the FAA-led study.

eLORAN actions

EQUIPMENT	PERFORMANCE	FUNCTIONALITY
• All tube transmitters will be replaced with solid-state transmitters • Older SSXs will be updated • New time and frequency equipment will be installed • New cesium clocks will be installed • New TCS and RAIL units will be installed • A monitoring network will be established for maritime differential corrections and far-field propagation effects. The network will include current SAM sites, Loran-C stations, and additional monitor sites as necessary for a given harbour • All stations may be dual rated • Some SAM sites will have a high accuracy clock for UTC synchronisation	• Momentary off-airs will be reduced to 3 seconds or less • Non-scheduled unusable incidents of > 3 seconds will be reduced to no more than 20 per station p.a. • ECD will be monitored and controlled to a tolerance of 200ns • When the parameters are out-of-tolerance, an off-air should be detected and transmitted within 2s • The probability of a failure to issue the alarm, given there is an OOT condition, will be less than 10^{-8} • Modulation of the transmitted signal will have minimal effect on navigation performance • Power interruption will not occur due to commercial power failure • Output power fluctuations will not exceed 5 percent	• A 9th pulse in each GRI will be broadcast. • The 9th pulse will provide differential corrections for maritime applications, as well as station identification and integrity for aviation • The Loran-C signal format will remain the same • TFE will support three kinds of phase adjustments: Local - Entered by an operator and take place over long period of time. Instantaneous local - discrete steps entered by an operator and take place instantaneously. Automatic - entered without operator intervention by the TFE control loop and take place over long period of time

So far, eLORAN is a US concept. If one now considers upgrading the *European* LORAN-C systems to eLORAN, and uses the US requirements as a checklist, the clear conclusion is that reaching eLORAN standard in Europe is feasible, and **the eLORAN concept** is equally **applicable in Europe**. In some respects, the upgrade to eLORAN would be more straightforward in Europe than in the US:

- most European LORAN stations, certainly all the former North West European LORAN System (NELS) stations, are already equipped with the solid state transmitters (SSX) needed to support eLORAN
- because many European LORAN-C stations, again including all the NELS stations, already employ Time-of-Transmission (ToT) control, they already have modern timing equipment (some very old equipment had to be replaced in the US upgrade)
- four European LORAN stations already carry a data channel, as would be required for eLORAN operation. A decision would be needed in Europe on whether to employ the current Eurofix standard or the 9th-pulse standard pioneered in the US. But even if Europe opted to use a different standard from the US, dual-standard receivers could be produced with little additional cost over Eurofix receivers
- there are fewer legacy LORAN-C users in Europe to be affected by the changes than in the US.

In rest of the world, the LORAN-C systems of the Far East, Middle East and Indian sub-continent (See Section 4.1) are much the same as those in the US or Europe. So, too, are the systems in Russia, allowing for the small differences between Chayka and LORAN-C. And, as in Europe, at least one Far East LORAN-C station and one Chayka station have already been successfully adapted to carry a LORAN data channel.

Thus, both in Europe and in the rest of the world, there is good evidence to support the view that LORAN-C could be upgraded to eLORAN and that a worldwide, standardised eLORAN service is an achievable goal.

1.4 Purpose of This Document

The GLAs have asserted that securing the future of LORAN - in its upgraded eLORAN form – is essential, and they have established an objective of:

> *"[Ensuring] the provision of an international, globally-standardised eLORAN PNT (position, navigation and time) multi-modal service, based upon interoperable multi-regional components both as a complement to GNSS and as a stand-alone backup in case of failure, by 2012"*

Achieving this objective will require actions on a number of fronts if the LORAN system is to be secured in both the short term and long term. But success will allow eLORAN to be included as a component e-Navigation, so that the maritime community will reap the full benefits of e-Navigation. An early action of the GLAs was to establish a new LORAN transmitter using an existing antenna at the Rugby Radio Station. This has radiated a LORAN signal on a test and development basis since July 2005. Initial differential eLoran trials conducted at Harwich in April 2006 have demonstrated horizontal positioning accuracies better than 9m with 95% confidence using modern, miniaturised eLoran receivers. This puts eLoran on the same basis as single frequency GPS or Galileo: each requires differential corrections to guarantee meeting the International Maritime Organisation's future accuracy requirements for port approach and restricted waters.

In addition, since LORAN is a regional system with transmitters distributed on a continental scale, there is clearly a need for the other European nations that currently operate LORAN stations to keep them on-air in a coordinated and synchronised system. Achieving this, and avoiding the loss of these stations following the ending of the NELS agreement (see Section 4.2), is a further objective of the GLAs.

eLoran must also make sense to governments, service providers and users. It must improve safety, meet IMO general navigation requirements and improve the cost-effectiveness of AtoN service provision. This document identifies and assesses qualitatively the benefits of a European eLoran service.

Section 2 will focus on the case for eLORAN in the maritime environment. Section 3 will introduce some of the potential benefits that eLORAN can bring to other modes of transport, especially on land, and demonstrate its importance for the national and international distribution of precise timing. In Section 4 the document describes the current state of LORAN around the world. Finally, this document is summarised in Section 5.

2 Delivering a Potential Maritime Radionavigation Dividend

2.1 Trends in Shipping

The maritime navigation environment is altering more rapidly than ever before. Over the last decade, there have been significant changes in shipping throughout Europe. They include increases in the size, speed, and numbers of ships, and also in the way vessels are operated. All these factors affect the requirements for maritime navigation.

New technology and techniques such as containerisation have resulted in much larger, faster, ships. At the same time, the number of seafarers needed on each vessel has fallen dramatically. Ships carrying standard-sized metal containers were first introduced in 1956: the principal benefit was the substantial reduction in the time required to load and unload the vessel. The switch to containers thus resulted in a sharp fall in costs, in reduced time for voyages, and in a reduction in the manual labour required. These benefits in turn encouraged increased globalisation.

Further technological advances since the introduction of containers have resulted in ships that are even larger and faster. The world's emerging economies – notably, China, India, Brazil and Russia – have boomed. This has presented opportunities and challenges to the freight transport industry that have resulted in an even stronger move to larger ships. As exports from these growing economies have increased year-by-year, the distances over which oil, bulk cargoes, chemicals and containers are transported have also risen. Unfortunately, in some areas, excess shipping capacity has now been provided leading to a realisation that concentration on larger ships could leave ship-owners vulnerable should there be an economic slow-down. Despite this concern, all current indicators point to further increases in worldwide seaborne trade, stimulated by growing consumer demand and the globalisation of production. According to World Bank estimates[4], sea trade will have grown at a rate of 4% per annum over the period 2000-2010. The result will have been a near-doubling of the total volume of seaborne trade by the end of this period.

Seaborne trade is increasing rapidly, and is set to continue to expand as emerging economies become ever stronger

Shipping is not only an expanding global business with significant investment opportunities, but also offers economic and environmental benefits. Not surprisingly, the governments of European maritime nations have demonstrated a wish to maintain their own shares of world seaborne trade. According to World Bank estimates, they are succeeding in doing so. In 2003, the volume of containers transported worldwide increased by 15.2%, to 90.9 million TEUs (full Twenty-foot Equivalent Units). Of these, 60 million TEUs passed through European ports.

Europe is on the frontline of shipping trade; it is involved in trade to, and from, the continent, and also in the intra-European movement of goods and in global cross-trades. Some 90% of Europe's merchandise is transported by sea. The figures are staggering: in 2004, the size of the registered trading fleet of the European Economic Area was 244.3 million DWT (dead-weight tonnes), 28% of the world's fleet tonnage, a figure that had increased by more than 50%[5] since the start of 2002.

Shipping is a key contributor to Europe's prosperity

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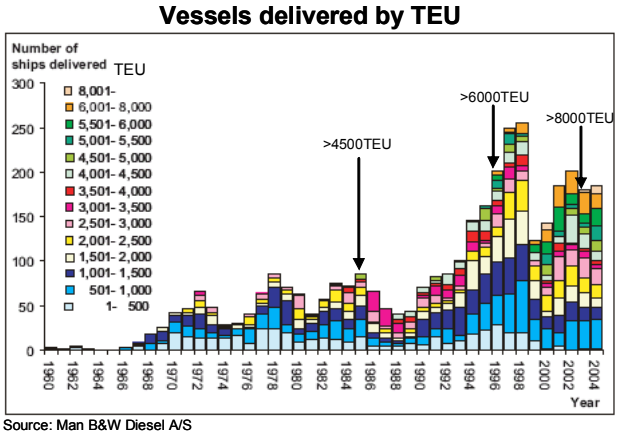
4 *British Shipping: Charting a new course, Department for Transport, White Paper, 24 November 2003, http://www.dft.gov.uk/stellent/groups/dft_shipping/documents/page/dft_shipping_505251.hcsp*

5 *Eurostat, 2004 data*

But traditional European shipping industries face increasing low-cost competition from abroad; shipping is a business that is relatively cheap and easy to enter. This has resulted in European governments' seeking ways to support their shipping industries, such as fiscal relief in the form of tonnage-based corporate taxation or the waiving of social charges for seafarers.

There is considerable downward pressure on shipping costs



Vessels delivered by TEU

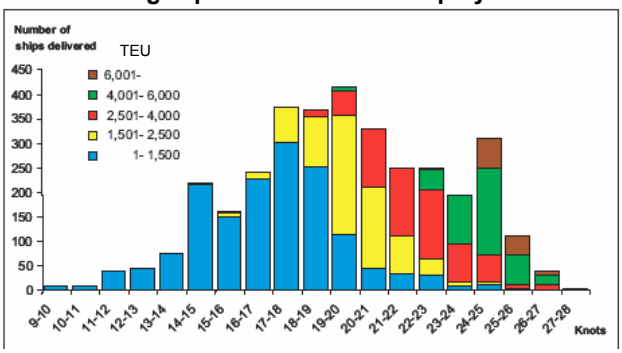
Source: Man B&W Diesel A/S
(TEU – twenty foot equivalent)

A lot of new ships are being built world-wide. At the end of 2004, the volume of new-build ship orders was equivalent to 20% of the existing fleet. And these new ships are big ships! In 1984, the largest vessels delivered had container capacities of only some 4500 TEU. By 1996, this had increased to 6000 TEU and in 2003, the first ships were delivered with capacities in excess of 8000 TEU.

The sizes of passenger and cruise vessels are growing, too. In June 2006 the company Royal Caribbean plans to launch a vessel of 158,000 tons, with accommodation for 3,600 passengers. Carnival has ordered 12 new ships to be built between now and 2009, each of them far larger than the average of the current passenger fleet. Indeed, there are reports of the company planning a 200,000-ton vessel, able to transport 5,000 passengers.

Ships – all kinds of ships - are getting larger

Bigger ships are also faster ships, something that has important consequences for navigation. The chart on the right shows the average speeds of vessels of various sizes. The large new container ships, carrying the equivalent of more than 6,000 containers, travel at some 25 knots. This is nearly twice the average speed of their smaller predecessors.



Average speed of container ship by TEU

Source: Man B&W Diesel A/S
(TEU – twenty foot equivalent)

The same trend is seen in passenger vessels. A super-fast ferry such as the SuperSeaCat is more than 100 metres long, carries 800 passengers plus 175 cars, and operates at 38 knots.

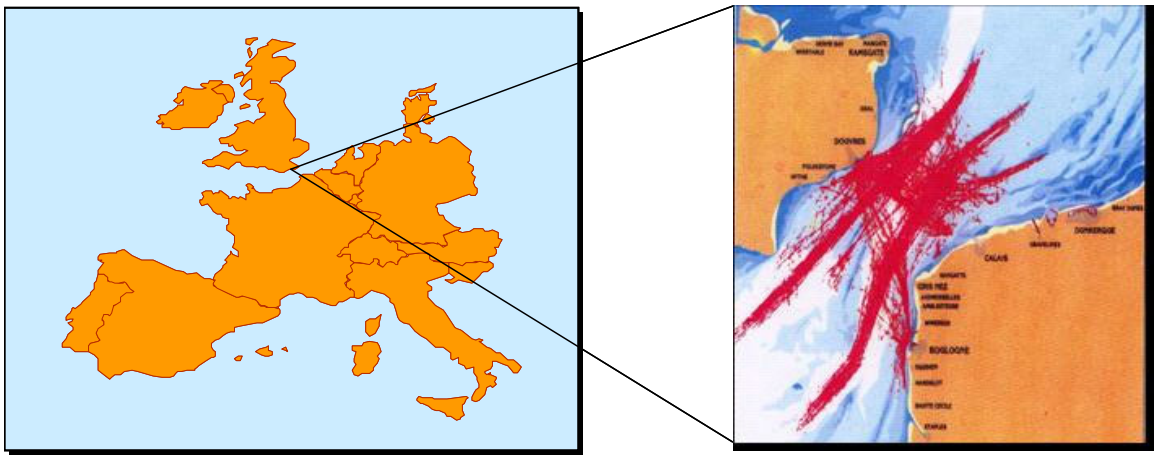
Ships are getting faster, too

As well as changes in the characteristics of seagoing vessels, their modes of operation have also been evolving. They are highly-automated, and their integrated bridge systems (IBS) allow just one man to run the bridge. In addition, carrier phase GPS has so increased accuracy (although not unfortunately availability, integrity or continuity) as to allow automatic berthing. As in aviation, the trend on ships' bridges is thus to heads-down navigation, via instrument displays. This raises major concerns as to what is likely to happen when such

systems fail. In the most serious scenario, the crew will simply not possess the necessary skills to revert to visual operation, either because they have never been trained to do so or because they lack recent training. Automatic docking is also likely to fail and the situation may well not be recoverable using manual means; an aviation parallel is a zero-visibility automatic landing in which the pilot would have no viable alternative other than a diversion if the navigation and guidance systems failed.

Reliance on automatic electronic navigation systems will become the norm

As would be expected in a growing transport industry, the concentration of shipping movements along the most efficient routes is increasing. Traffic densities at certain "pinch points", such as in the English Channel shown below, are now very high.



Marine hub and spoke operations
In a hub and spoke system of containerised seaborne trade, cargo to a region is delivered first to a primary hub port and then transported to its final destination, whether by sea, rail, road or inland waterways. Similarly, exports from the region are collected in the primary hub, then transported to final destination. While these primary ports are often equipped to allow for a quick turnaround time of vessels, there are usually two primary characteristics that set them apart from other ports: the primary hubs (a) tend to be geographically central to the region (sometimes with a substantial hinterland - that is, it attracts a considerable amount of cargo that would in any case flow through that port); and (b) can accommodate larger vessels than other ports in the region.
Source: World Bank

The nature of shipping is changing fundamentally: large vessels now ply trunk routes between hub ports. There, they transfer cargo to and from the smaller vessels that support local distribution. The economic justification for this hub-and-spoke operation is that the savings made through more efficient operation of the long-haul vessels outweigh the increased costs of double handling the cargo. The result, however, is that traffic is increasingly concentrated around the major ports.

Already high traffic concentrations will continue to increase around hub ports and at pinch points

2.2 Trends in ATON Provision

Under SOLAS Regulation V/13.1, governments have a statutory obligation *"…to provide … such aids to navigation as the volume of traffic … and… degree of risk require*". In meeting these requirements, the GLAs have taken into account the profound changes in the shipping industry highlighted above. Their response is clearly set out in the document *2020 The Vision.* This plan is being implemented by means of a developing radionavigation strategy, the principal components of which are:

- e-Navigation, as introduced above
- the electronic aids to navigation service information (e-ANSI) as a complement to the IMO/IHO (International Hydrographic Organisation) World-Wide Navigational Warning Service (WWNWS), to provide automatically real-time information to ships

on the status of aids to navigation that are critical for the safety of navigation and the protection of the marine environment. The concept is that the ECDIS or other suitable electronic display used on board the ship for navigational purposes will indicate when the operational status of an AtoN is changed. It will do so using the information received and via its display of the charts of the area. In particular, when an incident occurs and aids to navigation are used to mark uncharted wrecks or other new hazards, mariners will receive this essential navigational information promptly.

A number of systems form the kernel of these strategic components:

- GNSS, comprising GPS and Galileo, as a source of positioning and timing data
- radiobeacon DGNSS, to augment GPS and Galileo, principally in terms of integrity and accuracy
- AIS as the enabler for a number of applications:
    - AIS on AtoNs
    - synthetic AIS
    - virtual AtoNs, used for example to mark a wreck even before warning buoys have been deployed, so reducing the risk to mariners at the earliest stage;
    - providing the identities of AtoNs and confirming their operational status for the mariner;
    - broadcasts of the status of AtoNs to allow the service provider to monitor them;
    - broadcasts of meteorological or hydrological data to the mariner;
    - facilitating traffic analysis by AtoN providers so as to assist them in planning an appropriate level of service and mix of AtoN.
- eLORAN to assuage concerns about the vulnerability of GNSS in view of the total reliance of e-Navigation on electronic position fixing and timing. This data is a critical input to many of the systems and applications listed, including not only navigation, but also all the AIS applications listed above, vessel traffic monitoring, and casualty analysis.
- radar beacons (racons).

Implementing this strategy is expected to allow a substantial reduction in the numbers of physical AtoNs – buoys, lights, etc. It will also remove the need to deploy additional installations in the following situations:

1. to account for the increased reaction times needed by faster and larger vessels
2. to mark and re-mark new and shifting navigation channels.

The responses of the GLAs to these changes in the world of shipping and this new opportunity to replace traditional physical aids to navigation with more efficient, more rapidly-deployed and more cost-effective electronic systems, are the basis for the e-Navigation proposal, set out earlier.

Adopting e-Navigation is likely to result in a considerable financial saving because the number of physical AtoNs will be reduced.

Failing to implement e-Navigation will result in cost penalties, since additional AtoNs will be required.

A future e-Navigation system of the kind being considered would include all maritime navigation, surveillance and timing requirements. Navigation and timing could be provided

by GNSS alone. But to take that route would be to leave the mariner vulnerable to a single point of failure: the loss of GNSS. It would also be contrary to both common sense and good navigation practice, which is never to rely on a single source of information or data.

It is clearly essential that a future e-Navigation system be built upon secure foundations; if it were not, the GLAs would be obliged to retain at least the current level of physical AtoNs and more likely they would need to invest in additional infrastructure. The reasons for their being unwilling to depend on GNSS alone for e-Navigation will now be examined in detail. They apply whether the GNSS is GPS or Galileo, or both.

The benefits of e-Navigation would be severely eroded if the only source of radionavigation input were GNSS

2.3 Vulnerability OF GNSS - a Single Point of Failure

The vulnerabilities of GPS are well known and have been extensively documented in, for example:

- Volpe Report on GPS Vulnerability[6]
- Helios Technology, *Recommendations towards a European Union Radionavigation Plan*[7]
- Benshoof, *Civilian GPS systems and potential vulnerabilities*. CGSIC, Prague, March 2005.

The European Maritime Radionavigation Forum (EMRF) has also addressed GPS vulnerability, specifically in the maritime context. The results of their work are summarised in the following table in terms of the threat, the perceived risk, the consequences thereof and the difficulty in mitigating the threat.

Threat	Risk	Consequences	Mitigation difficulty/cost
System failure	L	H	H
Power supply failure	H	H	L
Receiver/antenna failure	M	H	L
Onboard interference	M	M	L
External interference	L	H	M
Ionospheric	L	M	M
Jamming	L	H	M
Spoofing	L	H	H

H = High. High risk means *likely to be encountered more than once a year*. High consequence means *complete loss of use of the system*. High difficulty or cost of mitigation means it is *unlikely to be achieved*.

M = Medium. Medium risk means likely to be encountered less than once a year. Medium consequence means system still usable, but degraded. Medium difficulty or cost means achievable at significant cost.

L = Low. Low risk means *unlikely to be encountered*. Low difficulty or cost means *mitigation should be achievable*.

Even though GPS is a highly reliable system, there are many examples of system failures that have led to degradation or loss of the GPS signal.

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6 "Vulnerability Assessment of the Transportation Infrastructure relying on the Global Positioning System", Final Report, prepared by John a Volpe National Transportation Systems Center for Office of the Assistant Secretary for Transportation Policy, US Department of Transportation, August 29 2001, http://www.navcen.uscg.gov/archive/2001/Oct/FinalReport-v4.6.pdf

7 System and Policy Inventory, Development of the European Radionavigation Plan, P377D004-1.0, Helios Technology Limited, prepared for the European Commission under contract ETU-B57000A-E4-193-2003 S07.26312-ERNP, 16 April 2004

GPS service degradation (EXAMPLE)

Location: Atlantic Ocean
Dates: 28 July -24 August 2000
Duration: 27 days 6 hrs 53 mins
Satellite SVN16 was removed from service because of instability within the spacecraft's atomic frequency standard clock. The satellite interruption caused a degradation of positioning precision to occur daily in the Atlantic Ocean. The duration of degradation varied from a few minutes to a maximum of 30 minutes. Some users may have experienced a momentary loss of signal during the period of the degradation. The affected area extended south from Greenland to Nova Scotia east to Europe and South East to the Canary Islands.

GPS service degradation (EXAMPLE)

Location: Large portions of Europe, Africa, Asia, Australia and far North America
Dates: 1 January 2004
Duration: 3 hours
On the 1st of January 2004, at approximately 1830 hours UTC, the Rubidium clock in the GPS satellite SVN23 failed causing the pseudo range error to increase to as much as 285 kilometres. The fault was not detected until several hours later and users were not warned until around three hours later. GPS receivers with RAIM were not able to detect this failure. However, DGPS stations configured to IALA requirements were able to detect the failure and provide normal services. Other DGPS stations ceased operations with consequent loss of position to users

GPS service outage (EXAMPLE)

Location: North America
Date: 28 October 2002
Duration: approximately 2 hrs
From about 1803 to1940 UTC, a satellite telecommunications company experienced timing outages across eastern Canada and the eastern United States. Air traffic control centres experienced Coded Time Source outages beginning about 1803UTC (no end time was reported). The USCG experienced some DGPS outages from about 1804 to 2000 UTC. A commercial wireless telecommunications provider experienced outages across the continental United States from about 1825 to1930 UTC. These outages were attributed to an anomaly in satellite SVN22@ timing being off by several seconds.

GPS outages and service degradation are more commonplace than are generally believed

If Galileo is used in conjunction with GPS, as it is likely to be once it becomes available, the number and frequency of system outages will be less than with GPS alone. Further improvements will result from the use of an integrity service that encompasses both systems.

GNSS has already been identified by terrorists as a potential high value target. The Volpe report states: "*As GPS further penetrates into the civil infrastructure, it becomes a tempting target that could be exploited by individuals, groups or countries hostile to the United States. The potential for denying GPS service by jamming exists. The potential for inducing a GPS receiver to produce misleading information exists.*"

News Flash – 21 April 2006

ATLANTA, Georgia (CNN) -- Two Atlanta-area men in federal custody as part of a terrorism probe discussed possible locations for a U.S. attack, including military bases and oil refineries, according court documents unsealed Friday…

….An affidavit from FBI agent Michael Scherck says the duo traveled in March 2005 from Atlanta to Canada, where they met with three men who are the subject of an FBI international terrorism investigation. Ahmed "explained that, during some of these meetings, he, Sadequee and the others discussed strategic locations in the United States suitable for a terrorist strike, to include oil refineries and military bases," the affidavit says. "**They also plotted how to disable the global positioning system in an effort to disrupt military and commercial communications and traffic**."…

GPS Jammers

…GPS "jammers," now available via the Internet for as little as $39.99, can easily interrupt the signal coming from the satellite system in a local area. At the Paris Air Show in 1999, a Russian company called Aviaconversia demonstrated a 4-watt GPS jammer, weighing about 19 pounds, capable of denying GPS reception for more than 100 miles. (By comparison, most hair dryers today have at least 18 watts of power.) …
Wall Street Journal, 24 September 2002

RADIXON HADRIAN RJ-G1575 GPS Jammer

"For sale only to government agencies, including law enforcement, and export destinations. Not for sale to U.S. civilian organizations, businesses or individuals.".
Special Order 4-6 weeks for delivery.

In addition to being a potential target of conventional terrorists, GNSS may well come under attack from more conventional criminals, from computer hackers and virus-writers, and even from motorists as it is increasingly employed to support *unpopular* applications such as road user pricing, and prisoner tracking (see Section 3). Low-cost, small GNSS jammers are now available. They are considered to be such a threat that even supplying or possessing them has been made a legal offence in Australia.

Case study – impact of a terrorist attack

In addition to direct impact, the terrorist attacks of 11 September 2001 severely disrupted the air transport system of the US for over a week. There was also a massive effect on foreign airlines with US services. In addition to the self-imposed shut-down of the air transport system, sea ports were blockaded. The costs of the shutdowns of the air and marine transport systems were estimated to have been some $50 billion, that is, as high as the direct costs at the World Trade Center:

- airlines lost millions of dollars (the US airline industry was brought to its knees)

- container shipping was estimated to have lost around a billion dollars a day, not only during the immediate aftermath but in the following months, as disrupted freight traffic was disentangled.

A jamming attack or other disruption on a sole means GNSS might be expected to have similar effects:

- there would likely be casualties caused by the breakdown of the transport system
- the immediate reaction of the authorities is likely to be to shutdown the transport system for a period much longer than the persistence of the direct threat
- there would be severe knock-on effects, since the shipping industry is a complex network
- as well as the obvious victims – marine and air transport – the other modes of transport could well suffer serious impacts.

Even if such an attack were short and only affected a single busy port, its direct and knock-on costs would be likely to run to millions of pounds.

The threat to GNSS through terrorist or criminal jamming is credible, real and likely to have significant economic and financial costs

In addition to intentional jamming, there is a real threat to GNSS from unintentional interference. A variety of types of legitimately-operated transmitter including commercial television and VHF stations, aeronautical and mobile satellite terminals, and ships' radars have been observed interfering with GNSS reception. There are even numerous instances of mal-functioning domestic receiving equipment radiating signals at or near GNSS frequencies that block GPS reception.

The Manatoulin Affair

in the early summer of 1996, repeated, apparently random failures of the DGPS receiver onboard the Manatoulin - a bulk carrier operating in the Great Lakes - caused the captain and crew to lose faith in both the reliability and accuracy of the ECDIS.

These failures caused the position of the ship, as displayed on the electronic chart, to move erratically and dramatically, often across large expanses of land. Usually the Speed Made Good display would start to increase, and sometimes indicate speeds of 500 knots or more.

The failures seemed to occur more frequently in particular places and when the vessel was travelling in a particular direction. Many other ships, several with equipment identical to that installed aboard the Manatoulin transited those same areas regularly, and without incident or failures of any kind, ruling out the possibility of external radiofrequency interference.

The source of interference turned out to be the television antenna for the captain's quarters. The antenna had an inbuilt RF amplifier built into the antenna, and is also directional, with a control located near the television that allowed the antenna to be pointed in different directions. The directional nature of the antenna exacerbated the RF noise problem when pointed towards a strong television signal, and reduced the problem when pointed away from a strong signal explaining why the interference only occurred when the ship was heading in certain directions.

Moss Landing Harbour

in April 2001 the GPS signal in Moss Landing Harbour, around 100km south of San Francisco, was jammed for a period of over a month. The jamming not only affected GPS position but also caused loss of timing information and, had there been foggy weather during the period would have inhibited navigation in the narrow harbour entrance.

Location of the source of interference was complicated by the extremely high multipath environment in the vicinity. However, eventually one source was identified as a commercially available VHF/UHF television antenna with built-in preamplifier configured such that the antenna was active even when the television was switched off.

A second source of interference was identified as another similar antenna from the same manufacturer configured so that it was only active when the television was switched on. Eventually a third similar antenna was isolated as an additional source of interference.

Some features of Galileo, notably its slightly higher transmitted power, make it a little more robust that GPS. However, because of the scarcity of frequency spectrum for GNSS and in order to allow low-cost receivers to accommodate both systems, Galileo will share frequency bands with GPS, the signals in some cases actually overlapping. This increases the likelihood that a signal – unintentional or intentional - that jams one of the systems will jam both. As the US Volpe Report states:

> *"Should … frequencies close to the GPS L1 and L5 … be chosen, it would appear that interference/jamming of GPS might well affect Galileo as well, thereby greatly reducing its ability to serve as a backup to GPS. In addition, Galileo's satellite signals will be about as powerful as GPS, making them also easy to jam."*

Ordinary radio-frequency emitters can cause severe interference to GNSS receivers, with effects similar to jamming

The impact of the loss of GNSS as a sole source of positioning and timing inputs in e-Navigation would depend on a number of factors, including the extent of the geographical area affected and the duration of the outage. For instance:

- prolonged outages covering wide areas would have severe safety, security, environmental, and economic effects because of the almost total reliance on GNSS (unaugmented or augmented) for positioning and navigation. Vital dependent systems such as AIS, which use GNSS position data and timing, would also be lost. Although systems, such as buoys and visual aids are widely deployed and would be available if GNSS were lost, we have seen that they would be incapable of supporting current volumes of traffic and certain types of operations such as high-speed ferries in restricted visibility
- even short-duration outages over large areas would have a severe impact on safety, security, the environment and economics, due to increased risks of collision, grounding and the loss of systems dependent on GNSS
- long outages over small areas would have a severe impact in that particular area. Some traffic would avoid the area
- short outages within confined areas, even area as small as an individual ship, would still involve danger and hazard to the environment, as exemplified by the grounding of the Panamanian-registered vessel Royal Majesty, which lost the GNSS upon which it was relying, off the Massachusetts coast in 1995.

There is no doubt that, if e-Navigation is to be employed, and is to deliver the benefits it promises, a second independent source of reliable and precise position and time information is essential. This source will have its own set of vulnerabilities; so they should be complementary to, and different from, those of GNSS (see Section 2.4). Only in this way, will the combination of GNSS and the reversionary source provide the exceptional levels of performance required by an e-Navigation system.

2.4 eLORAN as the Enabler

Based on the above, it is clear that e-Navigation employing GNSS alone will have severe limitations, particularly in the degree of trust that can be placed in its availability and continuity. The most obvious *second* radionavigation input to e-Navigation is eLORAN: its performance levels (Section 1.3) meet the requirements of maritime e-Navigation and its areas of vulnerability are very different from those of GNSS.

GNSS	LORAN
• Low power – vulnerable to electromagnetic interference • Operates at microwave frequencies • Line of sight propagation – blocked by obstacles • A positioning and timing system	• High power – robust against electromagnetic interference • Operates at low freqencies • Groundwave propagation – diffracts around obstacles • A positioning and timing system

> *"And look: the weaknesses of LORAN are so different from those of GPS. GPS is vulnerable to interference because the distant satellites deliver so little power to our receivers. LORAN, with its megawatt stations and tall transmitting antennas, is at least 10,000 times harder to jam. Then, you cut out single-point failures by using microwave signals from satellites and low-frequency signals from LORAN. On land, where buildings and mountains block GPS signals, LORAN travels along the earth's surface, deep into city centres, even into buildings and - for aviation - down into the valleys, to ground level. And like GPS, LORAN's a complete navigation and timing system."*
> Professor David Last

Together, GNSS and eLORAN are expected to provide an extremely robust positioning, navigation and timing solution. So, eLORAN emerges as the critical enabler of e-Navigation, the component that raises its performance to the level at which mariners can rely upon e-Navigation so that both they and the GLAs can safely enjoy the benefits it appears to promise.

These benefits are identified in the following list. It is recommended that they, and potential additional benefits, be studied in greater depth in the work that is to follow this preliminary White Paper. Those studies will explore and clarify the business case for eLORAN.

- **eLORAN to let the GLAs reduce the numbers of physical AtoNs:** increased reliance on automatic systems could allow some existing physical AtoNs to be removed
- **increased operational flexibility and improved safety in congested waters:** vessels may be able to operate at higher speeds and at closer separation in congested areas if eLORAN is used to guarantee the robustness of e-Navigation components such as vessel traffic services, automatic onboard collision avoidance systems and virtual aids to navigation. Virtual aids could be moved easily to accommodate prevailing traffic flows. Vessel traffic services (VTS) and onboard systems could be used to reduce the risk of collisions. Ultimately, we may see something akin to the maritime equivalent of air traffic control.

  In the absence of eLORAN, many of these benefits would not be achievable because of the lack of a fallback – should GNSS fail, the manual alternatives would not cope safely and extra physical AtoNs would be required
- **more efficient marking of wrecks using virtual aids.** This would enable wrecks to be marked immediately an incident was identified prior to deploying wreck marking buoys, so minimising response time
- **virtual aids to mark shifting channels and sand banks:** virtual aids could be used to mark channels, reducing the need for buoys and buoy tender time. This would result in operational benefits and cost savings, especially if used for those channels that shift rapidly due to moving sand banks. There, the virtual aids could be "moved" electronically without the need to dispatch a buoy tender
- **reduced inspection requirements for marking offshore structures:** offshore structures marked by means of electronic aids could be inspected remotely. This would reduce the ship time required for visits to inspect and mark them
- **eLORAN as an insurance policy against terrorist attack or unintentional interference:** clearly, given that its vulnerability to interference is so different from that of GNSS, eLORAN would make e-Navigation extremely robust against terrorist, criminal or unintentional jamming. Comparison with the knock-on transport disruptions impacts following the 11 September attacks, indicates that the value of this insurance policy could run to millions of pounds. It is recommended that this

benefit be evaluated in detail, using risk-based techniques, during the development of a business case for eLORAN

- **eLORAN as a critical input to safety nets:** accident statistics indicate that groundings and collisions are significant contributor to marine accidents. eLORAN would be essential to ensure the robustness of e-Navigation anti-grounding and anti-collision safety nets, especially as mariner increasingly come to rely on such safety nets rather than on traditional navigation techniques.

3 Other Applications of eLORAN

eLORAN has the potential to benefit users far beyond the maritime domain. There is a wide range of applications that for reasons of safety, contingency or commercial impact would benefit from an independent source of timing and position.

3.1 Total Reliance on GNSS

GPS has truly opened a Pandora's Box of positioning and timing applications in a way never before seen with conventional navigation systems. It has already become a ubiquitous utility of the 21st century. Now that GPS has found its way into consumer technologies, the public's appetite has been well and truly whetted. When combined with modern telecommunications systems, it can revolutionise personal mobility, transportation and timing. GPS is a marvellous technology. However, it is *not* a perfect one.

The problem presented by GPS is that it is generally so good; thus, it can be very difficult, or very costly, to provide a back-up that can support its wide range of applications in the event of a loss of signal. Clearly some applications are more vulnerable in their dependency on GPS, or to the deficiencies of GPS, than others. We discuss a set of these 'critical' applications in which a robust alternate to GPS would provide real benefits in the following sections. There are no doubt other applications too.

3.2 Timing and Synchronisation

Beyond the obvious applications of GNSS, are widely-used systems for synchronising telecommunications networks and managing their infrastructures. Many high-speed, wide-area networks that use synchronous communication protocols depend on GPS for their timing. GPS timing meets the top "Stratum 1" standard, at a relatively low cost, much lower over its lifetime than alternative products that employ atomic clocks.

3.2.1 Telecommunication Networks

For their synchronisation, telecommunications networks use highly accurate Primary Reference Clocks (PRCs) that must meet the international standard requirement for long-term frequency accuracy of better than 1 part in 10^{11}.

Large-scale synchronous communication networks, of the Synchronous Optical NETwork (SONET) or Synchronous Digital Hierarchy (SDH) types, can be synchronised in a variety of ways, utilising GPS. These include slaving a network of less accurate clocks to a GPS-based PRC. An alternative, more distributed approach, uses a series of network nodes, each synchronised to GPS. Alternate PRC timing sources such as Caesium clocks can be much more expensive than GPS, leading to an unhealthy dependence on the satellite based system.

Multiple GPS sources may be required because of problems that include variations of cable lengths from external GPS antennas, the loss of active GPS antennas due to lightning strikes, localised interference, and even signal blocking due to birds sitting atop antennas! However, these solutions do not mitigate against interference, jamming or other causes of total GNSS signal loss. For this purpose alternate technologies[8] are required.

eLORAN mitigates long-term outages of GPS, allowing robust networks to be built

[8] *LORAN is already one of the technologies complementary to GPS employed for timing. The ability of LORAN to operate using indoor antennas, something not possible with GPS, is also attractive, especially in sites where access to roof space is impossible or expensive.*

Accurate timing is also used in packet-switched, variable-latency networks, notably the Internet and other internal IP-based networks. The Network Time Protocol (NTP), one of the longest-established Internet protocols, can synchronise the clocks of all computers on a network to within 10 milliseconds via the public Internet. GPS is the primary timing source for most NTP products, with other timing sources used for "holdover" operation[9] (i.e. to keep them running if GPS is lost). The most robust systems that use MSF or DCF-77 holdover operate uninterrupted through GPS outages; the least, those using just quartz (OCXO) clocks, survive for some weeks only.

News Flash – April 2004

"… for security reasons a number of organisations (e.g. the US Defense Information Systems Agency) have decreased reliance on GPS NTP and are now users of Caesium clocks for NTP purposes to mitigate against the vulnerability of critical infrastructure."

In the mobile telecommunications industry, 3G, GPRS, CDMA and UMTS base stations are increasingly time-synchronised using GPS received at each station. All 3G base stations need 1 Pulse-Per-Second (PPS) inputs, with an accuracy of 3µs, to support the seamless movement of users between cells. The timing equipment generally features holdover based on dual sources of time; in the first instance the equipment can synchronise to an external time source distributed over an optical network (e.g. SONET or SDH); in the event of failure of that source the equipment should contain independent Stratum 2/3 sources, such as a rubidium (Rb) or OCXO clock. Hence, dual redundancy is provided in the event of a loss of GPS signal. But again, those SONET/SDH systems may well employ GPS timing, and Rb and OCXO oscillators also require a source of time to synchronise them.

For how long the performance of a mobile communication base station can be maintained, after it loses its local GPS signal, thus depends upon the accuracy of the holdover sources in use. Research[10] has shown that a typical 3G base station with an SDH external network source can continue for some 56 hours, plus an additional 24 hours if it also uses an internal Rb or OCXO oscillator. Therefore, typical 3G base stations should be tolerant of localised GPS signal losses for up to 3 days.

eLORAN can allow 3G mobile phone base stations to keep on running through medium-term losses of GPS signal that would otherwise put them off the air

Clearly, telecommunications networks depend strongly and increasingly on GPS for their synchronisation. The majority of networks employ holdover modes that at least protect them against short-duration losses of a local GPS signal. At best, they can continue independently of GPS. However, we have seen above that in the event of a wide-area loss of GPS, some of the alternative sources of timing would also be lost, since they too depend on GPS.

A recent US study by the US National Institute of Standards and Technology, with the US Naval Observatory, has shown that of the five widely-used Statum-1 timing sources in the US, only eLORAN and WWVB (which has significant practical disadvantages) are truly independent of GPS.

The greatest risk of all to communication networks is a long-term catastrophic loss of the core GPS constellation.

eLORAN therefore offers the telecommunication industry an insurance policy against major GPS failures. Its wide coverage, precise time capability, and indoor antennas are already available in combined GPS/eLORAN timing equipment.

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9 Holdover Mode is the capability of network Primary Reference Clocks to carry on producing a high quality output even when their main input reference (typically GPS) is lost. In Europe, holdover technologies include MSF or DCF 77 radio signals, plus disciplined ovenised crystal (OCXO) or Rubidium oscillators.

10 Schneuwly, D., "Robust GPS-Based Synchonization of CDMA Mobile Networks", Proceedings of the 33rd Annual Precise Time and Time Interval (PTTI) Meeting, pp191-198.

3.2.2 The Rugby MSF[11] Time Signal

In the UK, the MSF time signal broadcast from a VLF transmitter near Rugby, Warwickshire, (the same site that the GLAs are using to radiate Loran-C), is based on time standards maintained by the National Physical Laboratory (NPL). MSF is used by many industries to back up GPS as the primary means of timing. Users include telecommunications networks and UK railway station clocks. MSF supports a market for timing products of some £5M annually, providing VAT receipts to the UK Government of £900K[12].

NPL has been given Government permission to procure the MSF service for 10 years from 1 April 2007. But in addition, the Measurement Advisory Committee (MAC) of the UK Department of Trade and Industry (DTI) has recommended that the opportunity of collocating the MSF broadcasts with any UK LORAN transmitter be explored with a view to assessing whether LORAN could replace the MSF at the end of this contract. The need for the MSF will be reviewed in 2010, at which time a decision will be taken on its possible replacement by LORAN in 2017.

There is a window of opportunity to have eLORAN take over the provision of timing signals from the MSF.

3.3 Statutory Applications

In the Governmental domain, several positioning applications have redundancy or robustness requirements similar to those of safety-critical applications. They include electronic prisoner tracking, road user charging and emergency vehicle location. Such applications must be seen to be highly reliable if they are to retain public confidence as successful implementations of Government policy.

3.3.1 Electronic Prisoner Tracking

News Flash – 10 August 2005

Mirror.co.uk

£3MILLION PAEDO SPY FARCE
Sex offender tracker system doesn't work near tall buildings, trees or when it's cloudy

By Bob Roberts Deputy Political Editor

A SPY-in-the-sky system to track sex offenders is a disastrous failure, leaked documents reveal today.
Clouds, trees and buildings have all stopped police being able to follow convicted paedophiles and wife beaters.

The UK Criminal Justice and Court Services Act 2000 allows the tracking of offenders released on licence, to monitor their whereabouts or their compliance with other licence conditions. This Act also introduced the community sentence of an *exclusion order*, which may be monitored electronically. Offenders are typically monitored in three ways: ***continuous location monitoring*** – where there is a need to keep a constant watch on an individual, ***exclusion monitoring*** – where there is a need to know if an offender is breaking an exclusion order or licence condition at a time when prohibited from entering a given zone, and ***retrospective location monitoring*** – where there is a non-urgent need to know the whereabouts of an offender or of any breaches of an exclusion zone.

Currently a GPS unit coupled to a GSM telephone tracks the offender and communicates the data to the probation authorities. The prisoner must wear the tag at all times whilst outside home. However, this combination of technologies presents problems. GPS reception is often inadequate, the signals being lost inside buildings, in underground car parks, in urban canyons, and under dense foliage. This has led to some notable problems[13] in UK trials and resulted in significant negative publicity. Despite that, the trials have continued.

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11 The origins of the name are unclear but are generally believed to relate to the radio callsign of the station. However, Post Office staff that operated the station in 1951 insists that the name derives from the Modulated Standard Frequency scientific reference transmissions started in that year. Source: Wikipedia.

12 DTI Measurement Advisory Committee Report 2003-2004.

13 See, "GPS Monitoring Of Criminals Increasing", March 8th 2004, http://www.futurepundit.com/archives/001977.html

Some solutions to the vulnerabilities of GPS, such as GSM Cell-ID network positioning if the GPS signal is lost, have been proposed so making it more suitable for indoor positioning. However, Cell-ID positioning in towns may have errors of hundreds of metres and so is not a reliable means of assessing whether exclusion orders are being breached. eLORAN, on the other hand, could not only be easily integrated into such tagging devices but, when used in conjunction with GPS, would provide a robust and accurate means of locating offenders in many environments, urban and rural, with significantly higher accuracy.

eLORAN has the potential to reduce the well-known problems of offender tracking and together with GPS could make exclusion zone monitoring viable.

3.3.2 Road User Charging

Road User Charging (RUC) is a subject being examined, implemented and used in a variety of ways around Europe. It is likely that, at least in some cases, a system based primarily upon differential-GNSS will emerge. Any GNSS-based charging system would need high availability and high accuracy. Potential position errors would be felt financially by the vehicle owner – a sure-fire way of rapidly exposing deficiencies! A system that lacked robustness would be subject to vigorous legal challenge and would fail. Given the vulnerabilities and weaknesses of GPS in cities, integration with other sensors and technologies appears essential.

Where GPS based tolling systems have been implemented – such as in the German *Toll Collect* system – they have been deployed differently from the way expected in the UK. In Toll Collect, GPS identifies simply the instants when a vehicle passes known points at which tolling starts or ends. In the UK concept, the vehicle would be monitored throughout every trip.

eLORAN is clearly a candidate component of road tolling technology, combined with GPS, because of its high availability and its ability to penetrate into city centres and places such as fly-unders. In many locations, if the GPS signal were lost, the eLORAN signal would maintain the service. The accuracy of eLORAN alone might not be sufficient to support road tolling throughout an entire journey; however, it would be viable in applications such as Toll Collect, in which the vehicle's position is of interest at certain checkpoints only. Furthermore, combined GPS/eLORAN on-board units (OBU's) would be self-contained and might well not need any external odometer or other sensor. This would be less intrusive, easier to install, and also avoid the need to oblige car manufacturers to install units in the factory.

eLORAN is a robust complement to GNSS that could make road user charging less intrusive

Case study – the fallout from GNSS road user charging

Road user charging is expected to be contentious. Some will seek to interfere with the charging equipment for ideological or nefarious purposes. This could lead to an increase in the popularity and use of GPS jamming or spoofing equipment, which would affect the use of GPS for many other purposes. There are forums on the Web[14] for discussion of GPS jamming and spoofing techniques, with circuit diagrams and instructions for manufacturing jammers[15] as well as articles discussing the use of GPS spoofing in various potentially criminal activities[16].

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14 http://groups.yahoo.com/group/GPSHacking/

15 http://www.phrack.org/phrack/60/p60-0x0d.txt

16 http://www.eyefortransport.com/index.asp?news=38732&nli=freight&ch=

Products such as the one shown here are already available to target vehicle asset tracking and road user charging systems by jamming the GPS and GSM systems that together monitor the vehicle. However, the jamming effects of even such micro-powered devices will prevent all GPS tracking within at least a 50m radius and GPS signal acquisition over a much larger range. They could block safety-critical systems, including aviation systems.

GPS/GSM Jamming Equipment

http://www.detectnu.nl

The use of GPS in Road User Charging is making GPS jamming more likely.

3.3.3 Emergency Vehicle Tracking

GPS is increasingly being used for vehicle location, asset tracking and fleet management by emergency and law enforcement authorities. The majority of UK ambulances are already equipped with GPS moving-map displays for route guidance, and many also carry tracking systems. Some have used Datatrak for this purpose for many years. These systems are helping ambulance fleets improve efficiency and reduce response times, and so meet performance targets.

In those systems that employ GPS, it is necessary to integrate dead-reckoning devices such as accelerometers or gyroscopes to continue tracking through areas with poor, or no, usable GPS signals. A longer-term, or a wider-area, loss of GPS signals would prevent effective use of these vehicle tracking and dispatch systems. The potential for eLORAN is therefore clear. The technical similarities of LORAN to Datatrak (as used by the London Ambulance service) will help eLORAN in a market in which this other low-frequency system is well known and highly regarded. But the coverage of Datatrak is limited, even in the UK, where it extends only to England, parts of Wales, and the south of Scotland. eLORAN, in contrast, could cover many countries in which Datatrak will never be available.

High availability of position data is essential for ambulance tracking. Where GPS struggles, eLORAN will carry the load

3.3.4 eCall

The European Commission (EC) has recently proposed a pan-European automatic in-car emergency call system: eCall. This would require an on-board communications and positioning unit to be built into every new vehicle sold in the European Union (EU). When activated, by an onboard crash sensor the unit would automatically dial 112, report the vehicle's position and establish a voice connection with the emergency services operator so that situations could be evaluated quickly. If appropriate, the emergency services would be despatched to the precise location at once, so saving valuable time. The EC has set 2009 as the preliminary target date for the launch of eCall.

According to research[17], a system that provided emergency services with accurate details of the locations of incidents could save up to 2,500 lives per year across the EU. Resulting annual benefits in reduced accident and congestion costs are estimated at 21 billion, net of costs across the EU.

17 http://www.gstforum.org/en/subprojects/rescue/about_gst_rescue/introduction/e-merge.htm

The on-board equipment required to support eCall is still the subject of debate. Some propose an open-standard for both the positioning source and the communication links. GPS and Cell-ID are candidates at present. However, in this application the complementary performance of eLORAN would bring clear benefits for vehicles in inner cities, especially those parked in locations where GNSS is not available, such as multi-storey car parks. Ultimately, eCall may become a critical element of responses to accidents and may save many lives. These benefits demand accurate position data.

eLORAN could enable the benefits of eCall to be fully realised

3.4 Commercial Applications

In a number of applications of timing and positioning, the reliability of the data is critical.

3.4.1 Asset Tracking

Real-time, or near real-time, asset tracking is an increasingly prevalent and important application of GNSS technology that has already found broad market acceptance. Generally, the technology is used to support the efficiency of businesses, and is not mission-critical. But when it comes to the movement of time-critical, high-value or dangerous goods, that changes. The accuracy and reliability of the data become of vital importance in tracking security vehicles, delivery vehicles in Just-In-Time (JIT) production systems, or certain chemical tankers.

In all these applications there are common problems relating to GNSS satellite visibility, especially in cities. Even in less critical applications, the weaknesses of GPS may often prevent effective asset tracking. Tracking containers with GPS, for example, requires an external antenna with a good view of the sky. In many cases this is not practical, notably where containers are stacked on a ship or in a goods yard. The external antenna is also vulnerable to damage during transport and handling.

Recently, products have been developed for tracking that use LORAN[18]. They are self-contained, with no external antenna or power supply and can be mounted *within* a cargo container. They track the container everywhere that LORAN signals are available, outperforming all GPS or Cell-ID based solutions.

eLORAN can complement GNSS, ensuring that vehicles are tracked even where there's no GNSS

3.4.2 Lone Worker Protection

Lone workers in potentially dangerous environments such as on railway tracks or at remote telecommunication and power utility installations require protection, especially if their jobs involve hazardous activities such as scaling masts and pylons. Other categories of lone worker are health professionals operating in dangerous city areas who may need a 'panic button' facility. Current products for these people usually employ GSM or GPS/GSM technology. The GSM-only solutions are based upon Cell-ID, so tend to be less accurate in rural areas. This is a group of applications in which a robust back-up to the existing technologies is essential and in which eLORAN might have a really important role to play.

eLORAN could support lone workers, backing up GNSS in cities and GSM in the countryside

[18] *http://www.elsisag.com*

3.5 eLORAN as a Risk Mitigator

We have seen clearly in this Section just what eLORAN has to offer in a wide range of timing and positioning applications. GNSS and eLORAN are complementary to one another in so many respects (see Section 2.5 above); where one is at its weakest, the other may still be strong.

In timing, eLORAN may well be the only source wholly independent of GNSS. And even where it is not, it may be a cost-effective replacement for expensive atomic standards or niche-market systems such as MSF. It is also suitable for sale across Europe, the US and much of Asia. eLORAN also provides far more precise timing than MSF (better than 100ns) , and it comes from multiple stations, not just a single transmitter, so there is no maintenance down-time.

The table below summarises the consequence of the loss of GNSS for some of the applications considered above and shows how eLORAN can provide a solution, allowing them to continue working.

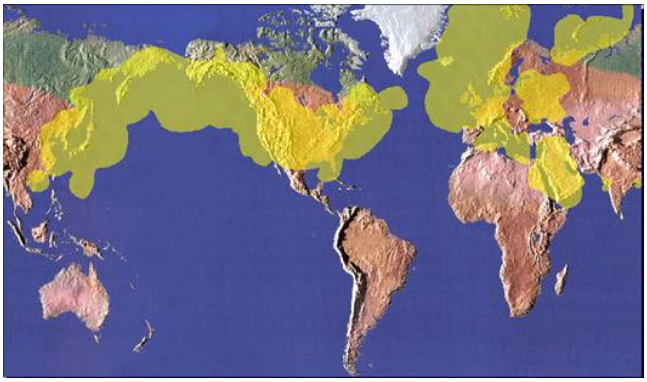
Scenario	Consequence of Loss of GNSS		
	Short Duration (minutes-hours)	**Medium Duration (hours-days)**	**Long Duration (days-weeks)**
Network Timing & Synchronisation	▪ No impact	▪ Some loss of synchronisation ▪ Reduced quality voice comms ▪ Higher error rate data comms	▪ Some major network outages ▪ Loss of some 3G base stations
Electronic Prisoner Tracking	▪ Loss of prisoner location ▪ No ability to detect exclusion zone penetration	▪ No knowledge of prisoner location ▪ Application no longer viable	▪ No knowledge of prisoner location ▪ Application no longer viable
Road User Charging	▪ Inability to position vehicles accurately ▪ Potential loss of tax revenue ▪ Potential for incorrect billing	▪ Loss of effectiveness of charging for congestion purposes ▪ Loss of tax revenue ▪ Loss of public confidence ▪ Application no longer viable	▪ Loss of effectiveness of charging for congestion purposes ▪ Major loss of tax revenue ▪ Total loss of public confidence ▪ Application no longer viable
Emergency Vehicle Tracking	▪ Nuisance factor ▪ Slight reduction in dispatch efficiency	▪ Reduction in dispatch efficiency ▪ Inability to meet service targets ▪ Possible additional cost from extra ambulances needed	▪ Reduction in dispatch efficiency ▪ Inability to meet service targets ▪ Application no longer viable
Asset Tracking	▪ Nuisance factor ▪ Slight reduction in dispatch efficiency	▪ Reduction in dispatch efficiency ▪ Necessity for expensive contingency measures or reversion to manual procedures	▪ Reduction in dispatch efficiency ▪ Necessity for expensive reversion to manual procedures ▪ Application no longer viable
eCall	▪ Lack of accurate position will delay locating accident ▪ Marginally reduced response times	▪ Inability to position vehicle renders application useless for major accidents	▪ Inability to position vehicle renders application useless for major accidents

Scenario	Consequence of Loss of GNSS		
	Short Duration (minutes-hours)	**Medium Duration (hours-days)**	**Long Duration (days-weeks)**
Lone Worker Protection	▪ Nuisance factor ▪ Necessity for reversion to manual service ▪ Lack of up-to-date position may delay emergency services	▪ Inability to position worker renders application of minimal use in major accidents	▪ Inability to position worker renders application useless for major accidents

4 The Route to eLORAN

4.1 Outside Europe

LORAN-C is a regional system: currently it covers a good deal of the Northern Hemisphere, approximately as illustrated in the figure. It serves all of the conterminous United States and much of Alaska, plus the coasts and populous areas of Canada. There is extensive service in the North Pacific, North Eastern Russian, and the Eastern cost of China, Korea and Japan, through the Far East Radionavigation System (FERNS). The Eastern Mediterranean and the Gulf Region receive signals from the recently re-capitalised Saudi Arabian chains. In the former Soviet Union, there is extensive coverage from the LORAN-compatible Chayka chains in Central and Northern Russia. It is clear that the demise of LORAN-C has been reported prematurely!



Since 1997, the US Congress has voted approximately US$160 Million for the LORAN modernisation effort. This has included funding the LORAN evaluations and GNSS/eLORAN receiver development. The recapitalisation of the US stations, involving the upgrading of equipment and the automating of the control systems, is expected to reduce operating costs; by how much is currently still uncertain. An additional US$25 Million of funding has recently been authorized for Financial Year 2007 (FY07)[19].

Despite this continuing high level of investment, the future of LORAN in the North America remains unclear. The current 2005 version of the Federal Radionavigation Plan (FRP) is not positive about the future of LORAN. The United States Coast Guard (USCG) has stated that it will not make budgetary requests to keep LORAN running and would like to terminate its LORAN operations by the middle of 2006; this statement is believed to be a response to financial difficulties with other, non-LORAN, projects. However, this USCG stance appears to be in conflict with US government policy, as stated in the FRP. There are currently discussions between The Department of Transportation (DOT) and the Department of Homeland Security (DHS) on this matter. In addition, questions are being raised a Congressional level concerning the Coast Guard's attempt to terminate LORAN in the light of the large sums that have been voted by Congress over recent years for its recapitalisation, and the funds approved for future expenditure. Ultimately the US decision on LORAN will be a high-level policy decision at DHS, DOT, and Presidential levels.

On a more practical level, LORAN transmitting equipment upgrades within the CONUS have been completed. The US is now conducting on-air tests to validate Time-of-Transmission Control and the LORAN Data Channel. The LORAN transmitting equipment in Alaska is being upgraded. Changes are expected in Alaska to the System Area Monitor (SAM) stations to provide advance warning of propagation anomalies, notably Early Skywaves and Sudden Ionospheric Disturbances (SID) effects. Unmanned monitor sites will also be required in the US for monitoring eLORAN signals and generating differential data for use in those waterways where HEA accuracies are required.

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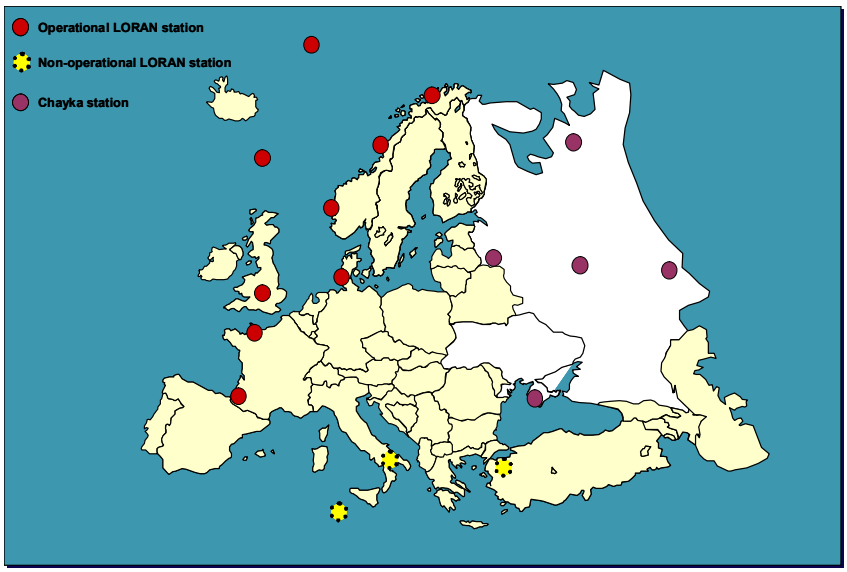
[19] Conference Report On H.R. 889, Coast Guard And Maritime Transportation Act of 2006, April 06, 2006

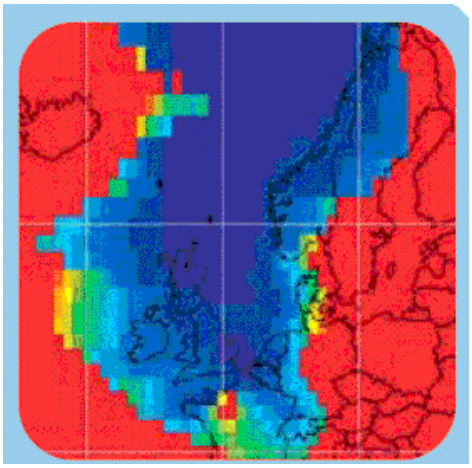
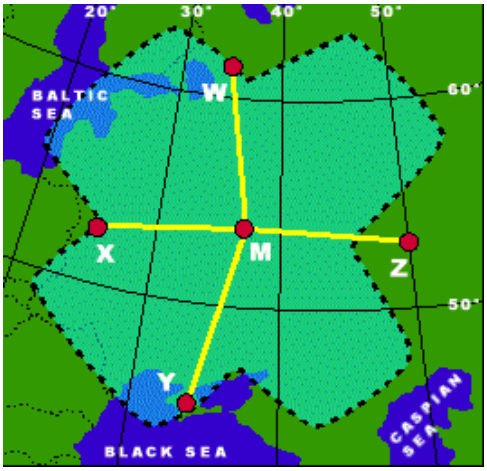
Worldwide, there has been considerable development of end-user equipment, especially the integrated GNSS-LORAN receivers that will be needed to implement eLORAN. Sitex Marine Electronics in Japan recently announced a GPS/WAAS/LORAN/DGPS receiver in which all the electronics are mounted within the base of the antenna unit [http://www.si-tex.com/html/gps_waas_loran_dgps.html]. A LORAN compass, accurate to approximately 1 degree is also part of this package. Integrated GPS/LORAN airborne receivers have been demonstrated, by Rockwell-Collins and Freeflight Inc, and their development is continuing. In Europe, an integrated GPS/LORAN receiver using two circuit boards of just credit-card size is now commercially available [http://www.reelektronika.nl/Loradd/ProdInfo.shtml].

4.2 In Europe

The European LORAN system (see figure below) is based on the NELS system with its 8 operational stations, plus the new experimental UK station at Rugby. In addition, there are 5 Chayka stations plus 3 non-operational LORAN sites of the former Mediterranean chain. Despite the dissolution of the NELS international agreement, all stations of the NELS system remain on the air, together with the control and maintenance centre station at Brest, France, and the new UK LORAN station.



As the two figures below show, the NELS system, together with the Rugby transmitter gives good LORAN coverage of North-Western Europe. The Western Russian Chayka chain gives covers that part of Europe roughly east of a line from the Baltic Sea to the Black Sea. Additional stations would be required to provide complete eLORAN coverage of all of Europe to the highest quality. It should also be remembered that traditional LORAN-C works in chains of stations synchronised together; receivers employ signals from the stations of a single chain at any time. Modern eLORAN receivers, however, operate in all-in-view mode, computing a best position solution from all stations they can receive, often more than 10. They weight the contribution of each station in accordance with its range and received signal quality (rather as a GNSS receiver does with satellites). Thus, better coverage will often be obtained from a constellation of stations when used in eLORAN mode than would be expected from a traditional LORAN-C coverage diagram.

NELS coverage with Rugby	Chayka coverage
 Source: Nottingham Scientific Ltd	

Looking to the future and the ERNP, the Helios Study *Recommendations towards a European Union Radionavigation Plan* estimates the costs of running and building LORAN stations as follows:

- annual operating cost of an eLORAN station ~ £300k
- cost of a new station, including transmitter and mast ~ £5000k.

Assuming an amortisation period of 15 years, the annual cost of a LORAN station would be around £600k, excluding the cost of capital.

The study also recognises the potential value of LORAN, and states:

- ✓ **The EU should work with Member States to investigate the European-wide provision of LORAN-C services in order to secure both transport and wider socio-economic policy benefits delivered by LORAN-C**
- ✓ **The EU should work with Member States to harmonise LORAN-C standards**
- ✓ **The EU should work with Member States to support the development of multi-modal receivers to ensure service take-up**

The Study concludes:

> *… LORAN-C/Eurofix delivers 22% of the policy benefits for only 4% of the annual total operational cost (8.5MEURO) …*
>
> *… LORAN-C is the only real stand-alone alternative to satellite radio-navigation services for many market sectors (including maritime, land and timing). Its dissimilar use of spectrum mitigates many of the vulnerabilities associated with satellite radio-navigation L-band interference and provides robust coverage in areas of limited GNSS availability (e.g. urban). It is also provides through Eurofix a DGNSS data delivery mechanism for Europe …*

The future of the European system remains uncertain. If the recommendations just set out are to be implemented, we need to recognise certain clear short-term milestones. First, the German Government will decide shortly whether to close down and mothball its Sylt station

or come to an agreement with its neighbours for its continued operation in the short term. The Norwegian Government has agreed already taken such a step. It will keep its four stations, Værlandet, Bø, Berlevåg, and Jan Mayen, on the air throughout 2006, in recognition of the renewed interest in LORAN in Europe and in view of the forthcoming Europe-wide decisions to be made on the ERNP. However, in June the Norwegian Government will need to make a budgetary decision regarding future manpower for its stations. Of all of the European governments, the French is the most positive. France has made a clear statement of its intention to retain its two stations plus the control and maintenance centre at Brest. This is partly to meet is own, defence-driven needs, but also in recognition of the growing civil role for LORAN. France has also undertaken to support the continued operation of the station at Ejde on the Faroe Islands and is concluding contract negotiations accordingly with the Danish Government

The decisions made by these individual Governments – particularly Norway and Germany – made in advance of the ERNP discussions, could greatly influence the future for eLORAN across Europe as a whole. Once a station has been switched off, restoring it is much harder. Once a station has been dismantled and the site cleared, it is unlikely ever to be reactivated. The German stations, and at least one of the Norwegian stations, are of paramount importance for the coverage of the British Isles and its coastal waters. If these stations go off the air, it will be very difficult for the GLAs to provide an adequate eLORAN service in their area of responsibility. It is therefore of great importance that the GLAs provide detailed information to the relevant German and Norwegian stakeholders not only to justify a stay of execution on the operation of their stations but also to provide concrete proposals for renewed investment in eLORAN.

On the UK domestic front, the operation of the Rugby transmitter also needs to be extended beyond the end of 2006 in order to secure the transition of the system from LORAN-C to eLORAN.

4.3 Upgrade to eLORAN

The current European stations employ LORAN-C or Chayka technology and would need to be upgraded to an eLORAN standard, broadly in accordance with the US model of eLORAN.

The following table adapts the US *Recommendations for Follow-On actions*, to show the corresponding European requirements, resulting in a list of actions:

(US) Action	Actions in Europe
Prior to an ERNP decision	
Identify areas of direct savings or cost avoidance that could be invested into eLORAN.	The present and related maritime studies are in response to this requirement. Similar studies should encompass the use of eLORAN for other modes of transportation and for timing and frequency use.
Support R&D to identify additional critical applications in which safety, security, and economic concerns must be met in the event of a GPS or Galileo outage. Determine whether eLORAN would be practical and beneficial (e.g., in supporting the critical timing/frequency infrastructure).	Europe should monitor the on-going US programme and initiate equivalent European studies and actions, as required.

(US) Action	Actions in Europe
Prior to an ERNP decision	
Get an ERNP decision to develop a Europe-wide eLORAN system with an identified source of funding	This is the object of the present study and the set of actions of which it forms a part
Definitively announce the Federal Government's policy to continue in the long term the modernized LORAN-C system.	Definitively announce an EU policy to establish and operate in the long term an eLORAN system as part of Europe's critical infrastructure for position, navigation, and timing/frequency applications. This announcement – especially if there has been a corresponding announcement in the US - will initiate the development of LORAN equipment and encourage further advances in LORAN technologies It is expected that the same low-cost receivers will serve US, European and world markets.
Ensure a diverse and competitive supply of multi-functional user equipment in the near term and throughout the life of the system.	
Conduct a design study to identify the locations of additional new LORAN stations plus existing LORAN stations that will need updating.	Conduct a design study to identify the locations of additional new LORAN stations plus existing LORAN or Chayka stations that will need updating. The Helios ERNP study estimated that to obtain full coverage into all corners of the European Maritime Coverage Area, additional stations might be required in Sweden, Lithuania, the Czech Republic, Romania, Turkey, Egypt, Italy, France, Algeria, Portugal, Madeira, and the Canary Islands. A coverage prediction model suitable for European conditions would also be required.
Promote the further understanding, development, and adoption of the system.	This will require the production and dissemination of information and training material.
In creating the European eLORAN system	
Revise inter-agency and international agreements	Create international agreements to support the European eLORAN system.
Implement time of transmission control	Update existing stations outside the NELS network to Time of Emission control. Additional new stations would be built to this standard.
Complete the installation of the solid-state transmitters (SSX).	Update existing stations outside the NELS network to Time of Emission control. Additional new stations would be built to this standard.
Complete harbour and airport surveys.	The number of surveys, and the magnitude of each one, is currently being determined in US studies. Airport surveys might not be required in Europe.

(US) Action	Actions in Europe
Develop international standards for eLORAN	
Rewrite the LORAN-C Signal Specification, updating it to eLORAN.	This would involve modifications to existing documents of the: ITU (Technical Characteristics & Spectrum Requirements), IMO (Performance Standards & WWRNS Recognition), IEC (Equipment Test Standards), and IALA (Operational Standards for Service Providers). GAUSS, RTCM and ETSI could help facilitate the process, particularly for receivers.
Develop receiver specifications for NPA, HEA, and other applications, as required.	
Rewrite the LORAN-C Operational Doctrine.	This would draw on preparatory work conducted in the US.
Continuing studies	
Further investigate noise and propagation effects to allow for less conservative estimates that better define the system capabilities and improve the LORAN models.	Europe would monitor the on-going US programme and, if necessary, extend it to meet European needs.
Periodically update benefit/cost assessment data and expand its scope to include business cases for each GPS redundant, back-up, and contingency system, as well as each option for PNT.	Europe would monitor the US programme (which is continuing) and initiate equivalent European actions, as required.
Investigate other methods that analyze and determine a PNT application's performance requirements (e.g., target levels of safety).	Europe would monitor the on-going US programme, the results of which are likely to be directly applicable to Europe.

In addition, a study will be required in Europe leading to a decision on the form of eLORAN data channel to be implemented: Eurofix or US 9th pulse. This will determine whether receivers are required to support either of these standards, or just a single standard.

4.4 Securing the Future

When the actions to deal with institutional and LORAN station matters set out Section 4.3 are undertaken, receiver developers will be stimulated to invest in development and production of integrated GNSS/eLORAN equipment. This will make receivers cheaper and more widely available.

5 Summary

The shipping industry is changing: ships are getting bigger and faster, operational processes are evolving, and traffic density in already-congested areas is increasing yet even more. Intense competition is putting ship owners and operators are under pressure to reduce their operating costs, not least in what they pay for aids to navigation. With the ready availability of GPS, the art of navigation is shifting towards total reliance on electronic systems, with a concomitant loss of traditional skills. Even if the numbers of physical aids to navigation were increased, it appears that conventional means of navigation would be unable to cope in this emerging marine navigation environment.

The concept of e-Navigation offers a potential solution. However, e-Navigation based on GNSS (GPS and Galileo) is unlikely to be sufficiently robust and reliable, given the well-documented vulnerabilities of GNSS to intentional and unintentional interference. Terrorism, criminal acts and accidental electromagnetic jamming have been shown to be real and credible threats to GNSS and so to the systems that rely on it for positioning and timing.

Loss of GNSS, where it provides the sole position and timing input to e-Navigation, could have catastrophic results. A terrorist attack on GNSS could have direct and knock-on costs totalling millions of pounds; even unintentional interference may result in marked reductions in safety and considerable inconvenience. So, if e-Navigation remains vulnerable to interruption, its potential cost savings will be largely negated. It will not, as hoped, prove possible to reduce the numbers of physical aids to navigation. Indeed, more of them may be needed, to cope with increased traffic volumes and larger, faster, ships.

eLORAN, offering properties complementary to those of GNSS, provides the ideal second input to e-Navigation, removing its exposure to the vulnerabilities of GNSS. In fact, there is no realistic alternative to eLORAN in doing this. Work already undertaken in the US, and trials being conducted in the UK, have shown that eLORAN has the performance to fulfil this role. eLORAN, then, can be viewed as the critical enabler for e-Navigation. Specifically, the benefits it offers the maritime world include:

- a reduction in the numbers of physical AtoNs, and so in their maintenance costs. Without this, the number and cost of physical AtoNs might be expected to increase
- more efficient and flexible shipping operations, especially in congested areas
- quicker, safer, and more cost-effective marking of wrecks and channels using virtual aids to navigation
- reduced costs to the General Lighthouse Authorities for the inspection of offshore structures that are marked using virtual aids to navigation
- increased safety by providing robust electronic safety nets, including collision avoidance and anti-grounding systems.

Specifically, eLORAN would provide an insurance policy against the potentially massive impacts of terrorist or criminal jamming attack on GNSS.

For other areas of transport, eLORAN could support safety-critical and mission-critical positioning and timing systems, not only reducing their vulnerability to GNSS failure but also providing a reversionary capability. It would expand the scope of such systems into applications that GNSS alone simply cannot cover. However, some of these applications – such as electronic prisoner tracking and road user charging – are likely increase the incentive for criminal or malicious attempts to disrupt GNSS signals. Even short-term outages of the position and timing inputs to road user charging, electronic prisoner tracking or the planned eCall response to emergencies, would cause severe nuisance, or even complete loss of the service. Other yet more critical applications, such as telecommunications network synchronisation would be degraded or removed by longer-

duration, or wider-area, outages of the input timing signals. In meeting the needs of this critical infrastructure, eLORAN has better performance than conventional low frequency timing services such as MSF.

The infrastructure to provide an adequate eLORAN service across North West Europe mostly exists and is already operational. It would need to be upgraded from its current LORAN-C or Chayka technology to eLORAN. This change has already largely happened across North America and would also be feasible worldwide wherever there are legacy LORAN systems.

Given the nature of area-coverage systems such as LORAN, pan-European coordination of the infrastructure is essential. The European Radionavigation Plan (ERNP) is expected to recognise this, to identify LORAN as a trans-European service, and to propose the Europe-wide coordination and funding of eLORAN. Unfortunately, in Europe since the ending of the NELS agreement, the future of LORAN has been increasingly uncertain. Norway and Germany are expected to make decisions as to whether or not to continue the operation of their stations in time-scales shorter than those of the EU ERNP process. The loss of these key existing facilities before Europe has made its decisions on eLORAN would be highly regrettable. The governments of Norway and Germany are strongly encouraged to continue to provide signals from their stations until the eLORAN cost-benefit analysis has been concluded and a Europe-wide decision on the future, and funding, of eLORAN agreed. Remember: the ERNP study concluded that LORAN could deliver 22% of the policy benefits of the ERNP for only 4% of the cost.

When the actions to deal with institutional and LORAN station matters set out in this document are undertaken, receiver developers will be stimulated to invest in development and production of integrated GNSS/eLORAN equipment. This will make receivers cheaper and more widely available.

A Glossary of Terms

3G	Third Generation
AIS	Automatic Identification System
ASF	Additional Secondary Factor
AtoN	Aid to Navigation
CDMA	Code Division Multiple Access
CIL	Commissioners of Irish Lights
CWI	Carrier Wave Interference
DCF-77	German 77 kHz timing service
DfT	UK Department for Transport
DGPS	Differential GPS
DHS	US Department of Homeland Security
DoT	US Department of Transport
DTI	UK Department of Trade and Industry
DWT	Dead Weight Tonne
e-ANSI	Electronic Aids to Navigation Service Information
EC	European Commission
ECD	Envelope to Cycle Differences
ECDIS	Electronic Chart Display Information System
eLORAN	Enhanced LORAN
EMRF	European Maritime Radionavigation Forum
ERNP	European Radionavigation Plan
ETSI	European Telecommunications Standards Institute
EU	European Union
FAA	Federal Aviation Administration
FERNS	Far East Radionavigation System
FRP	Federal Radionavigation Plan
GLA	General Lighthouse Authority
GLF	General Lighthouse Fund
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRI	Group Repetition Interval
GSM	Global System for Mobile Communications
HEA	Harbour Entrance and Approach
IALA	International Association of Martine Aids to Navigation and Lighthouse Authorities
ID	Identity
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
ITU	International Telecommunication Union
JIT	Just In Time
LORAN	Long Range Navigation
MAC	Measurement Advisory Committee
MSF	UK 60 kHz Timing Service

NELS	Northwest European LORAN System
NLB	Northern Lighthouse Board
nm	Nautical Mile
NPA	Aviation Non Precision Approach
NPL	National Physical Laboratory
NTP	Network Time Protocol
OBU	On Board Unit
OCXO	Quartz (clock)
OOT	Out Of Tolerance
PNT	Position Navigation and Time
PPS	Pulse Per Second
PRC	Primary Reference Clock
RACON	Radar Beacon
Rb	Rubidium
RAIL	Remote Automated Integrated Loran
RNAV	Radionavigation
RTCM	Radio Technical Commission for Maritime Service
RUC	Road User Charging
SAM	System Area Monitor
SDH	Synchronous Digital Hierarchy
SOLAS	Safety of Life at Sea
SID	Sudden Ionospheric Disturbance
SONET	Synchronous Optical Network
SSX	Solid State Transmitters
TCS	Transmitter Control Subsystem
TEU	Twenty-foot Equivalent Unit
TFE	Timing and Frequency Equipment
TH	Trinity House
ToT	Time of Transmission
UK	United Kingdom
UMTS	Universal Mobile Telecommunications System
US	United States of America
USCG	US Coast Guard
UTC	Co-ordinated Universal Time
VAT	Value Added Tax
VHF	Very High Frequency
VLF	Very Low Frequency
VTS	Vessel Traffic Service
WWNWS	World-Wide Navigational Warning Service
WWRNS	World-Wide Radionavigation System
WWVB	US 60 kHz timing service