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Briefing Note: Evolution from Loran-C to eLoran

Executive Summary

This paper has been prepared by the Research and Radionavigation Directorate of the General Lighthouse Authorities of the United Kingdom and Ireland for the European eLoran Forum.

The purpose of this briefing note is to provide a meaningful comparison of Loran-C and eLoran.

Definitions are proposed for different generations of Loran to assist the comparison: USCG Loran-C, Modernised Loran-C, Prototype eLoran and eLoran.

The different generations of Loran are compared in terms of their capability, performance and functionality.

Upgrading from Modernised Loran-C (e.g. NELS) to Prototype eLoran (e.g. GLAs) requires (i) Eurofix now used to carry UTC, differential Loran and enhanced integrity messages, (ii) measured Additional Secondary Factors (ASFs) stored in the receiver, and (iii) differential Loran reference stations for maritime and precise timing. The GLAs' prototype eLoran system has been in operation for more than a year. The GLAs understand that Vaerlandet and Bø are suitable for prototype eLoran given that each station already has Eurofix installed.

Upgrading to eLoran will require (i) an updated control system and monitor receiver at each station and switch cabinets and/or uninterruptible power supplies at certain stations, (ii) Eurofix at all stations, and (iii) modernised control at Brest.

The Rough Order of Magnitude (ROM) costs for upgrading from Modernised Loran-C to Prototype eLoran are: €160k for Eurofix at those stations that do not yet have it; €65k for each differential reference station; and €65k for each set of ASF surveying equipment.

The ROM cost for upgrading from Prototype eLoran to eLoran is €500k per station: the precise upgrade will depend on future requirements and the current configuration of the station. No attempt has been made to estimate the hardware and software costs for the Control Centre.

1 Introduction

This paper has been prepared by the Research and Radionavigation Directorate of the General Lighthouse Authorities of the United Kingdom and Ireland for the European eLoran Forum.

The purpose of this briefing note is to provide a meaningful comparison of Loran-C and eLoran.

High-level definitions are proposed for different generations of Loran in Section 2 to assist the comparison. In Section 3 these different generations are then compared in terms of capability (Section 3.1), performance (Section 3.2) and functionality (Section 3.3).

No attempt is made in this document to compare the different generations of Chayka.

Rough Order of Magnitude (ROM) costs for upgrading from Modernised Loran-C to Prototype eLoran and from Prototype eLoran to eLoran are given in Section 4.

2 Definitions

Any discussion of the difference between Loran-C and eLoran is complicated because Loran-C has been modernised at different times and to different extents in different parts of the World. The definitions in Table 1 are proposed to assist the comparison.

USCG Loran-C	The original version of Loran-C (c. 1960s) based on tube transmitters, SAM control, ASF look-up tables and hyperbolic navigation, requiring large numbers of people on site. Typical accuracy: 460m (95%).
Modernised Loran-C	The original version of NELS (c. 1990s) based on solid-state transmitters, time-of-emission timing, ASF model, hyperbolic or rho-rho navigation, and requiring very few people on site. Typical accuracy: 100m (95%).
Prototype eLoran[1]	The GLAs' system (c. 2008) based on modernised Loran-C together with (i) Eurofix to carry UTC and differential Loran, (ii) all-in-view navigation, (iii) precise ASF surveys, and (iii) differential Loran reference stations for maritime use. Typical accuracy: 10-20m (95%). Real-time prototype eLoran has been in operation for two years and is now running continuously.
eLoran[1]	This is the future (c. 2013?) based on prototype eLoran together with (i) updated station equipment to improve timing stability, (ii) mitigation of vulnerabilities to ensure high availability, (iii) Eurofix at all stations, and (iv) modernised control at Brest. Typical accuracy: 10-20m (95%).

Notes:

1. All generations of Loran support Stratum 1 frequency for telecommunications. Prototype eLoran and eLoran support UTC time of day. eLoran will support sub-50ns precise timing.

Table 1: Definitions of different generations of Loran

3 Comparison

3.1 Capability

The capability of each generation of Loran is compared in Table 2 by considering the applications it supports. It is important to note that user requirements have become more stringent over time.

Supported Application	USCG Loran-C	Modernised Loran-C	Prototype eLoran	eLoran
Resilient PNT[1]			[3]	✓
Maritime: Ocean[2]		✓	✓	✓
Maritime: Coastal & Harbour[2]			✓	✓
Aviation: Non-Precision Approach				✓
Stratum 1 Frequency	✓	✓	✓	✓
UTC			✓	✓
Precise Timing			[3]	✓
Land Mobile[4]			✓	✓
Interference Detection & Mitigation[5]			✓	✓

Notes:

1. PNT – Positioning Navigation and Timing. Resilient PNT (e.g. based on GNSS + eLoran) is emerging as the requirement in many sectors. The UK Centre for the Protection of National Infrastructure uses the following definition for resilience: the equipment and architecture used are inherently reliable, secured against obvious external threats and capable of withstanding some degree of damage. Prototype eLoran does not yet have full availability due to existing operational procedures.
2. Maritime requirements based on: International Maritime Organisation Resolution A.953(23) [1].
3. Full performance precise timing is not available due to the timing steps used for station synchronisation. Use of frequency steering in eLoran should enable continuous sub-50ns timing.
4. 20-30m (95%) vehicle accuracy has been obtained in central London in conjunction with map-matching.
5. Interference Detection and Mitigation (IDM) is increasingly important. The UK's GAARDIAN project is doing this by comparing GPS, eLoran and clocks.

Table 2: Application supported by different generations of Loran

3.2 Performance

The performance of each system is compared in terms of accuracy, integrity and availability in Table 3.

Performance	USCG Loran-C	Modernised Loran-C	Prototype eLoran	eLoran
Accuracy (95%)	**460m**	**100m**	**10-20m**	**10-20m**
Integrity	**Low**	**Moderate**	**High**	**High**
Availability	**Low**	**Moderate**	**Moderate**	**High**

Notes:

1. Accuracy: The Table shows the approximate value of the absolute accuracy achievable across the specified coverage area by a receiver that uses ASF corrections. The most demanding accuracy specification met by eLoran is that required for maritime harbour entrance. eLoran achieves its high accuracy by means of: "all-in-view" receivers that track multiple stations and employ advanced signal processing; precise ASFs measured in harbour surveys; and real-time differential Loran corrections generated at reference stations and transmitted over the data channel.
2. Integrity: The measure of the trust that can be placed in the correctness of the information supplied. It includes the ability of the system to provide timely warnings to users when the system should not be used for navigation. The most demanding integrity specification met by eLoran is that required for non-precision aviation instrument approaches. The much higher integrity of eLoran compared to Loran-C is principally due to the rapidity of its response to system failures. Signals are monitored continuously and warning messages passed promptly to the receiver via the data channel.
3. Availability: The percentage of time the services of the system are usable by a navigator within the specified coverage area. The most demanding availability specification met by eLoran is that required for non-precision aviation instrument approaches. The much higher availability of eLoran, compared to the earlier versions of Loran, has been achieved by numerous improvements in the transmitting station infrastructure and operational procedures. Not all of these have been implemented in Prototype eLoran. The other major contributor to eLoran's high availability is the use of "all-in-view" receivers that track multiple stations, rather than the 3-station triads of Loran-C.

Table 3: Performance delivered by different generations of Loran

3.3 Functionality

The eLoran service (Figure 1) is based on a Core eLoran Service and Augmentation Service, as outlined in the International Loran Association's eLoran Definition Document [2].

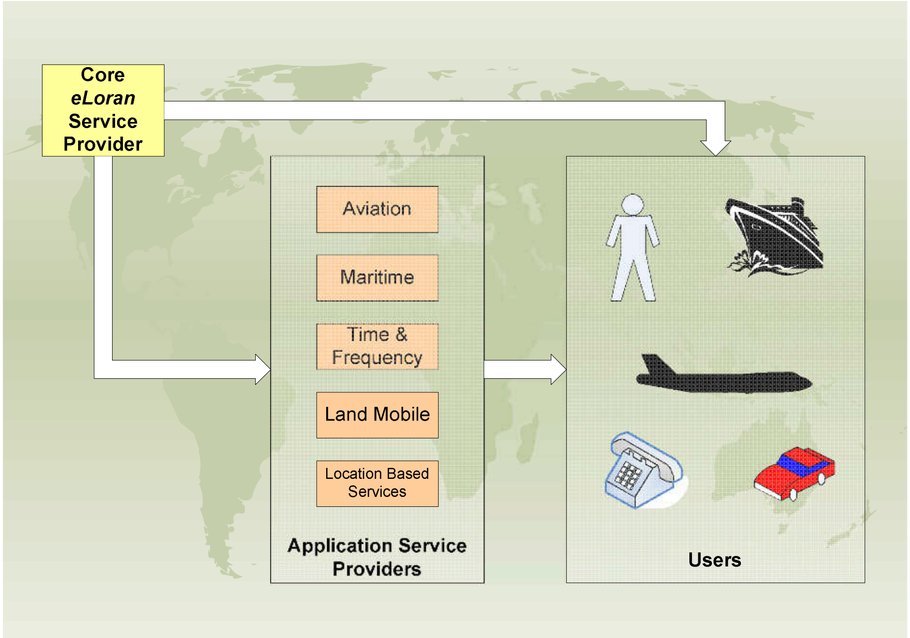

Figure 1: eLoran service provision

The Core eLoran Service comprises the control centre(s), transmitters and monitoring stations. It delivers a highly precise version of the core signal essentially described in the US Coast Guard Specification of the Transmitted Loran-C Signal [3].

The Application Services comprise differential and other monitoring stations and deliver application-specific data (e.g. maritime differential Loran messages or aviation early skywave warnings) that may be communicated using a data channel (e.g. Eurofix) on the eLoran signal.

This allows flexibility for eLoran to provide different types of service in different regions. It also allows liability to be managed within individual modes of application. An example showing the eLoran service provision for maritime users is presented in Figure 2.

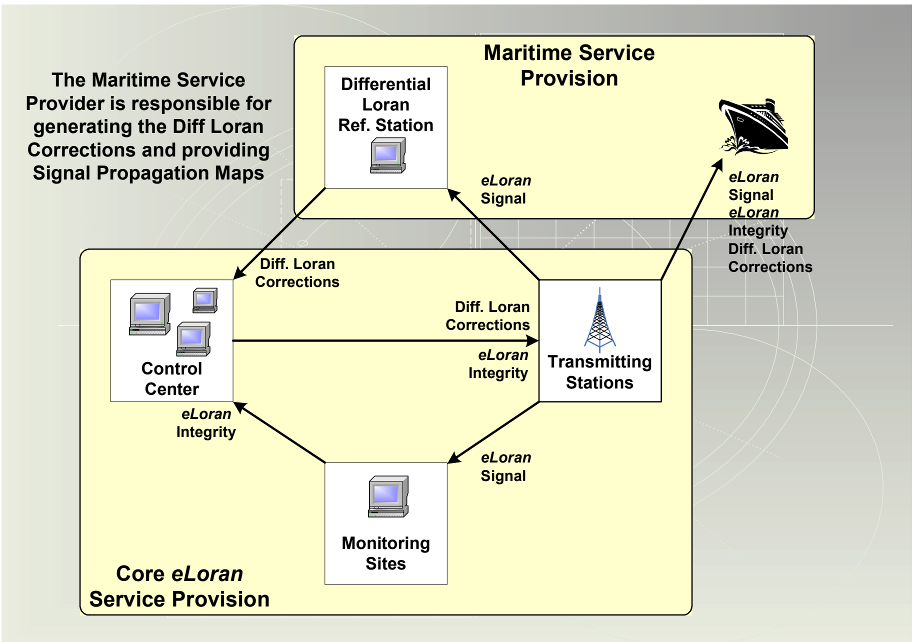

Figure 2: eLoran maritime service provision

The functionality of the different generations of Loran is compared in Notes:

1. Full performance precise timing is not available due to the timing steps used for station synchronisation. Use of frequency steering in eLoran should enable continuous sub-50ns timing.

Table 4, grouped by Core system, Augmentations and User equipment.

Function	USCG Loran-C	Modernised Loran-C	Prototype eLoran	eLoran
Core system				
Remote control		✓	✓	✓
Tube transmitter	✘			
SAM control	✘			
Solid-state transmitter		✓	✓	✓
Time-of-emission timing		✓	✓	✓
Time-stepped synchronisation	✘	✘	✘	
Frequency-steered sync.				✓
Fast Blink for Integrity				✓
Augmentations				
Eurofix carrying eLoran data			✓	✓
Differential reference stations			✓	✓
Rapid integrity messaging				✓
User equipment				
Navigation: Hyperbolic	✘	✘		
Navigation: All in view TOE			✓	✓
ASF: Look-up tables	✘			
ASF: Computer model		✘		
ASF: Surveyed and stored			✓	✓
Receiver: Stand-alone Loran	✘	✘		
Receiver: Integrated with GNSS			✓	✓
Precise time			*1*	✓

Notes:

2. Full performance precise timing is not available due to the timing steps used for station synchronisation. Use of frequency steering in eLoran should enable continuous sub-50ns timing.

Table 4: Functionality of different generations of Loran

4 Cost

4.1 From Modernised Loran-C to Prototype eLoran

Rough Order of Magnitude (ROM) costs have been estimated for the capital items required for the upgrade from modernised Loran-C to prototype eLoran. These are presented in Table 5.

Item	ROM Cost
Eurofix per station	€160k
Differential reference station	€65k
ASF surveying equipment	€65k

Table 5: ROM costs for upgrading from modernised Loran-C to prototype eLoran

4.2 From Prototype eLoran to eLoran

ROM costs have been estimated for the capital items required for the upgrade from prototype eLoran to eLoran. These are based on modernising European-type stations; similar activity has been undertaken in the US. The precise upgrade at each European station will depend on future requirements and its current configuration. The costs are presented in Table 6. No attempt has been made to estimate the hardware and software costs for the Control Centre.

Item	ROM Cost
Transmitter control system, switch cabinet, uninterruptible power supply and monitor receiver per station	€500k

Table 6: ROM costs for upgrading from prototype eLoran to eLoran

5 References

[1] World Wide Radionavigation System, International Maritime Organisation, Resolution A.953(23), 2004

[2] 'Enhanced Loran (eLoran) Definition Document', International Loran Association, V1.0, 16 October 2007

[3] 'Specification of the Transmitted Loran-C Signal', United States Coast Guard, COMDINST M16562.4A, 1994