eLoran

Securing Positioning, Navigation and Timing for Europe's Future

Prepared by the European eLoran Forum, April 2008

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Executive Summary

This document has been produced by the European eLoran Forum for policy-makers, service providers and users. It sets out the strategic importance of positioning, navigation and timing (PNT) systems that underpin our European critical infrastructure and emphasises the role of Enhanced Loran (eLoran) as a way of making our European PNT foundations robust and resilient.

Robust, reliable and high-performance positioning, navigation and timing (PNT) are the lifeblood of a modern society's critical infrastructure: power systems, telecommunications, transport and finance. The future prosperity and welfare of Europe is underpinned by this critical infrastructure – but it is dependent upon the Global Positioning System (GPS).

GPS has revolutionised PNT and the combination of Galileo and GPS promises enhanced performance efficiencies. However, like all satellite navigation systems, GPS and Galileo share common vulnerabilities at signal and user levels, for example to interference and jamming. eLoran, a terrestrial radionavigation system, fully independent of GPS & Galileo and delivering comparable levels of performance, does not.

The US has already accepted eLoran's role as a key component of its future PNT mix: the world's premier satellite navigation service provider knows its own vulnerabilities, has done extensive analysis and has settled on eLoran as the solution. Even Bradford Parkinson, the respected "Father of GPS", is quoted[1] as saying,

> *"The ultimate compliment to GPS is that it is taken for granted … A contingency augmentation, like eLoran, is essential and would act as a deterrent to terrorism."*

Other satellite navigation service providers have a similar PNT mix: the Russian Federation operates its GLONASS satellite navigation system and its version of LORAN, Chayka; and the People's Republic of China is developing its Compass satellite navigation system and has deployed LORAN in the Far East. In Europe, eLoran can perform a similar supporting role to the eagerly awaited Galileo system.

In determining its long-term PNT mix Europe needs a mature and rational debate about GNSS vulnerability that recognises both the benefits of having two satellite navigation systems, Galileo and GPS, as well as the benefits of system diversity based on eLoran.

The development and operation of the European eLoran infrastructure is currently being undertaken on an *ad-hoc* basis. The importance of eLoran's supporting role to GPS and Galileo needs to be assessed within the context of a European Radio Navigation Plan. Using these three PNT systems together will protect our critical infrastructure and allow our European service providers and users to retain the safety, security and economic benefits of GPS that they currently enjoy even when their satellite services are disrupted.

Detailed Appendices are available on request from R&RNAV@thls.org

1 *US National Space Based PNT Executive Board minutes, 29-30 March 2007*

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1 Introduction

1.1 Scope

This document has been produced by the European eLoran Forum (EEF) for policy-makers, service providers and users. It sets out the strategic importance of the positioning, navigation and timing (PNT) systems that underpin our European critical infrastructure and it emphasises the role of Enhanced Loran (eLoran) as a way of making our European PNT foundations robust and resilient.

1.2 The European eLoran Forum

The EEF is an *ad hoc* group of European organisations that have an interest in eLoran because they currently operate, fund or host eLoran infrastructure. Current members include the Danish Maritime Safety Agency[2], France, and the General Lighthouse Authorities of the United Kingdom and Ireland[3]. Its purpose is to support the successful introduction, operation and provision of eLoran services in Europe as part of a European Radio Navigation Plan.

1.3 Background

Our society depends on the efficient working of power generation and distribution systems; information and communications technologies, telecommunications; banking systems; and transportation. These are recognised by the European Commission as critical infrastructure.

These critical infrastructures and their enabled applications are heavily and increasingly dependent upon PNT. PNT underpins telecommunications (timing), financial markets (timing) and fleet logistics (position, navigation and timing) as well as transport (position, navigation and timing). Knowledge of position and time remains vital for the development of trade and commerce in Europe and globally. Therefore, the importance of PNT to Europe cannot be overstated. However, despite this importance, it is often taken for granted that accurate position and time will always be available.

The ever-increasing reliance on accurate position and time by these 'critical infrastructures' has been driven by the capabilities afforded by the GPS. PNT through GPS has become ubiquitous and essential. In the future, GPS and Galileo will rightly form the cornerstone of the future European PNT environment. However, GPS vulnerability is universally understood. Galileo will ameliorate this vulnerability to a degree by allowing users to retain PNT when there are GPS system failures and *vice versa*. However, both GPS and Galileo have well-known common modes of failure: e.g. signal interference and jamming.

Therefore, to ensure the continuous availability of PNT and hence enable the reliable and robust operation of critical infrastructure, the common vulnerabilities of GPS and Galileo need to be addressed. The solution? A cost effective, complementary, dissimilar technology that does not share these vulnerabilities - eLoran.

1.4 Purpose

The purpose of this document is to outline the safety, economic and critical infrastructure protection benefits of eLoran in the broadest sense to European policy-makers, service providers and users who may have responsibility for funding, specifying, operating and using the future radionavigation infrastructure.

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[2] *The Danish Maritime Safety Administration (DMSA) hosts the Ejde station, currently funded by France*

[3] *Norway is an observer.*

2 The strategic requirement for PNT

2.1 Critical infrastructure – the lifeblood of modern society

Recognising that the future health and welfare of Europe is underpinned by critical infrastructure, the European Commission (EC) has launched the European Programme for Critical Infrastructure Protection (EPCIP) to complement national initiatives by eliminating weak points in infrastructure that spans European borders.

"The security and economy of the European Union as well as the well-being of its citizens depends on certain infrastructure and the services they provide. The destruction or disruption of infrastructure providing key services could entail the loss of lives, the loss of property, a collapse of public confidence and morale in the EU. Any such disruptions or manipulations of critical infrastructure should, to the extent possible, be brief, infrequent, manageable, geographically isolated and minimally detrimental to the welfare of the Member States, their citizens and the European Union."[4]

The EPCIP will require critical infrastructure operators to develop security plans and work on appropriate risk mitigation strategies.

2.2 What happens when critical infrastructure fails?

The urgent need to protect critical infrastructure is easily understood when the impact of its loss is assessed in terms of disruption and cost. The following examples provide an indication of the economic and financial impact of infrastructure outages. Of course, these impacts may also be exacerbated by safety and environmental effects.

Loss of broadband networks
The loss of accurate timing within broadband networks can cause significant problems. Initially, degraded timing performance leads to an increase in transmission errors between networks, slowing data transfer. Then as timing synchronisation breaks down altogether failures of entire networks can occur. The impact of telecommunications outages has been illustrated graphically by the recent damage to sub-sea cables in the Mediterranean and the Gulf Region. These breakages caused major disruption to internet traffic in Egypt, the Gulf and South Asia. Even though the service outages were very short and rapidly ameliorated by re-routing, the economic impacts were reported as very severe. A theoretical study of the impact of internet outages in Switzerland[5] (a fairly intensive internet country) indicates that an outage, caused by a deliberate denial of service (DDOS) attack, is likely to cause negative economic impacts to the Swiss economy of approximately: ▪ 310 million Swiss Francs (**~€200 M**) for an outage of 24 hours ▪ 5.8 billion Swiss Francs (**~€3.5 B**) for an outage of one week. If such an outage occurred across several countries, these already considerable losses would be multiplied significantly. Simple scaling from the results for Switzerland, accounting for GDP and broadband penetration, indicates that the combined cost of a broadband outage of 24 hours in Denmark, France, Germany, Netherlands, Norway and the UK might be as high as **€3.4 billion**.

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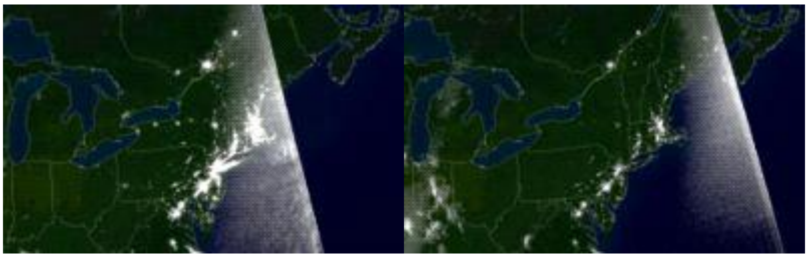
4 *European Commission communication on the European Programme for Critical Infrastructure Protection (EPCIP)*

5 *An Economic Damage Model for Large-Scale Internet Attacks,* Thomas Dubendorfer, Arno Wagner, Bernhard Plattner, Computer Engineering and Networks Laboratory (TIK), Swiss Federal Institute of Technology, ETH-Zentrum, CH-8092 Zurich

Loss of power systems

Accurate timing information is critical in today's electricity distribution networks to control the efficiency of supplies and to help diagnose faults. Without high quality PNT, distribution efficiency can be reduced and outages can take longer to diagnose - all potentially leading to more frequent, longer duration blackouts.

Satellite imagery of day before, and day of, 2003 N.E. US blackout



On August 14, 2003, large portions of the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout[6].

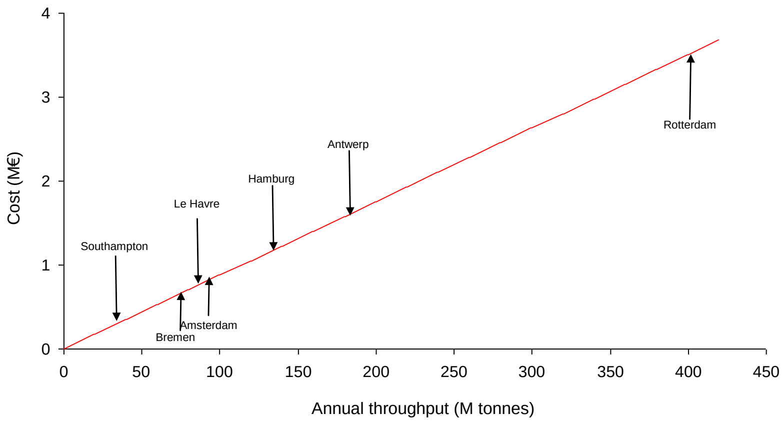
The outage affected an area with an estimated 50 million people and a demand for 61,800 megawatts of electricity. The blackout began a few minutes after 4:00 pm Eastern Daylight Time, and in some parts of the United States power was not restored for 4 days. Parts of Ontario suffered rolling blackouts for more than a week. The blackouts effectively shut down the automobile manufacturing industry, petroleum refineries, and steel and chemical industries in the states affected.

The cost of a blackout to the electricity companies and to industry and society as a whole can be extremely high. Estimates[7] of the total costs of these events in the United States ranged between US$4 billion and US$10 billion (**€2.5 billion to €6.3 billion**). In Canada, the gross domestic product during the month of the blackout was down by 0.7%, there was a net loss of 18.9 million work hours, and manufacturing shipments in Ontario were down C$2.3 billion (€1.6 billion).

Loss of a major sea port

A 2001 study[8], based on US data, indicated that each day's saving in shipping time was valued by the importers as being worth 0.8% of the value of the goods. Conversely, every day delayed would cost the importer 0.8% of the value. Based on certain assumptions it is possible to estimate the cost of a day's disruption at major European sea ports.

Estimated cost to a port of 24 hours disruption causing 50% capacity loss for cargo transport



These costs are conservatively estimated to be in the range **€0.5M to €3.5M per day per port** depending in the size of the port.

6 *"Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations," U.S.-Canada Power System Outage Task Force, April 5, 2004.*

7 *The Economic Impacts of the August 2003 Blackout, Prepared by the Electricity Consumers Resource Council (ELCON) - February 9, 2004.*

8 Time as a Trade Barrier, *David Hummels,*

Failures in marine navigation

Recent evidence from one of the leading marine insurers, the Norwegian Hull Club, directly links the rise in the number of accidents at sea with human and navigational error. The NHC's statistics show that between 2002 and 2006, groundings and collisions accounted for 21% of claims by number but 37% by cost.[9] So, how expensive can marine accidents be?

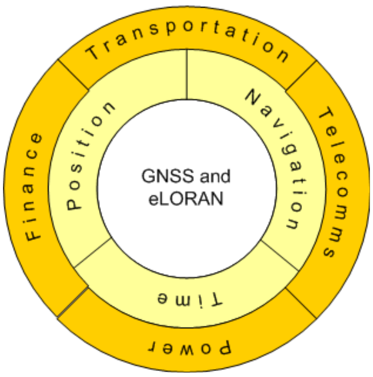
The MSC Napoli was damaged in a storm in Jan 2007. It was then intentionally beached at Branscombe, Dorset to minimise its potential environmental impact. The subsequent salvage and clean-up operation has to April 2008 cost **£65M (€85M)** and is yet to be completed. Only £15M (€20M) of the costs were insured by the vessel's operators potentially leaving local tax payers and Government exposed to the remaining costs.

In March 1989, the Exxon Valdez oil tanker ran around in Alaska, spilling more than 32,000 tonnes of oil and creating a 12-mile oil slick. Billed as one of the worst environmental disasters ever, it was costly for Exxon in several ways. The clean up cost alone was over **$2 billion** and in 1994 a federal jury also fined Exxon an additional **$5 billion** for its "recklessness," the largest fine ever for corporate irresponsibility, which Exxon later appealed against.

2.3 PNT is the core enabler

Not only is PNT a critical infrastructure in its own right, but PNT services are also a significant component in many other critical infrastructures, such as energy (power distribution), communication (fixed, mobile, broadcasting) and even in financial industries (securities clearing). PNT is also likely to be at the core of many developing applications in the future.

PNT underpins the modern economy



The economic impact of the failure of individual critical infrastructures has been highlighted above. Their reliance on PNT is growing both individually and collectively. The impact of a failure of PNT will, therefore, not affect a single sector but will have a knock-on effect across the many sectors that it supports. The individual impacts could be multiplied manifold. Hence, there is a growing need to recognise the importance of PNT to critical applications and infrastructure and to act to ensure its resilience in the future.

2.4 PNT must be 'always on'

To mitigate the risk of multiple failures on critical infrastructure leading from a failure, accidental or deliberate, of PNT, the provision of PNT must be robust, resilient and continuously available.

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9 Crew quality hits marine claims. *Lloyds List, No 59650, 14 April 2008*

3 Making PNT robust & reliable

3.1 Today's limitations

A number of studies have examined and documented GPS vulnerabilities, the most significant of which was the 2001 US DoT Volpe report[10]. Volpe recognised that GPS cannot serve as the sole source for position, location or precise timing in critical applications. The report was explicit in its declaration that US public policy must ensure that safety is maintained in the event of the loss of GPS. Volpe also identified GPS as an increasingly tempting target for exploitation by “malicious persons” that could result in safety, service, financial and environmental impacts. In assessing the ease with which GPS services could be denied (even in 2001, since when its vulnerability has increased) Volpe’s assessment was brutal in its honesty:

> *“GPS jammers exist in a variety of sizes and output power levels. Small, lightweight, short- lived jammers with power from 1 to 100 watts can cost less than $1,000. These jammers can be built by people with basic technical competence from readily available commercial components and publicly available information.*
>
> *At the other end of this threat spectrum is the potential for large numbers of mass-produced, low cost, and low power jammers. Factories in foreign countries that are currently producing consumer products can easily be modified to produce thousands of jammers per day. Hundreds could be distributed in a single area of GPS denial.”*

The Volpe Report recommended that backups be provided, using combinations of terrestrial, space-based and on-board equipment together with appropriate operating procedures. It was therefore clear – at least within the US and as early as 2001 – that over-dependence of some applications on GPS had been recognised. Thereafter, actions were put in place to reduce the impact of the system’s weaknesses. The recent US Department of Homeland Security decision[11] to continue to support the development of an eLoran capability was based upon the need to provide a credible back up to GPS for critical infrastructure.

3.2 The solution: complementary systems

Rightly, modernised GPS and Galileo will form the core of the global PNT system. Together, possibly enhanced by augmentation systems, these systems will overcome some of the systemic vulnerabilities of GPS alone, e.g. system failures in one or other of the satellite constellations. However, both systems operate in essentially the same way and some of the fundamental weaknesses remain, particularly the low power signals that are susceptible to interference and jamming, blocking by buildings or trees, and propagation anomalies.

To overcome these vulnerabilities, a system is needed that is not subject to the same weaknesses – it should be diverse, complementary and use a different infrastructure. The most obvious complementary radionavigation system to GNSS is eLoran whose areas of vulnerability are very different from those of GNSS.

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10 *Vulnerability Assessment of the Transportation Infrastructure relying on the Global Positioning System, Final Report, Aug 29, 2001. Prepared by John A. Volpe National Transportation Systems Center.*

11 *Statement from DHS Press Secretary Laura Keehhner on the adoption of national backup system to GPS, US Department of Homeland Security, February 7, 2008.*

GNSS

- Low power – vulnerable to electromagnetic interference
- Operates at microwave frequencies
- Line of sight propagation – blocked by obstacles
- A positioning and timing system

LORAN

- High power – robust against electromagnetic interference
- Operates at low freqencies
- Groundwave propagation – diffracts around obstacles
- A positioning and timing system

3.3 eLoran system overview

Enhanced Loran is an internationally-standardised positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It is the latest in the long-standing and proven series of low-frequency, LOng-RAnge Navigation (LORAN) systems, one that takes full advantage of 21st century technology.

eLoran meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbour entrance and approach manoeuvres, land- mobile vehicle navigation, and location-based services. It is also a precise source of time and frequency for applications such as telecommunications. eLoran provides equivalent accuracy (8 - 20 metres) and timing (stratum-1) performance to current GPS.

eLoran Predicted Performance

Accuracy	Availability	Integrity	Continuity
8 – 20 metres	99.9% - 99.99%	1 x 10^{-7} per hour	99.9% to 99.99% over 150 seconds

The core eLoran system comprises modernised control centres, transmitting stations and monitoring sites. eLoran transmissions are synchronised to an identifiable, publicly-certified, source of Coordinated Universal Time (UTC) by a method wholly independent of GNSS. This allows the eLoran Service Provider to operate on a time scale that is synchronised with, but operates independently of, GNSS time scales. Synchronising to a common time source also allows receivers to employ a mixture of eLoran and satellite signals.

3.4 The global PNT consensus

Globally the need for a backup PNT capability for critical infrastructure has been recognised by numerous PNT providers, with the notable exception of Europe. Many of those who have accepted this need already have, or aim shortly to have, a GNSS constellation.

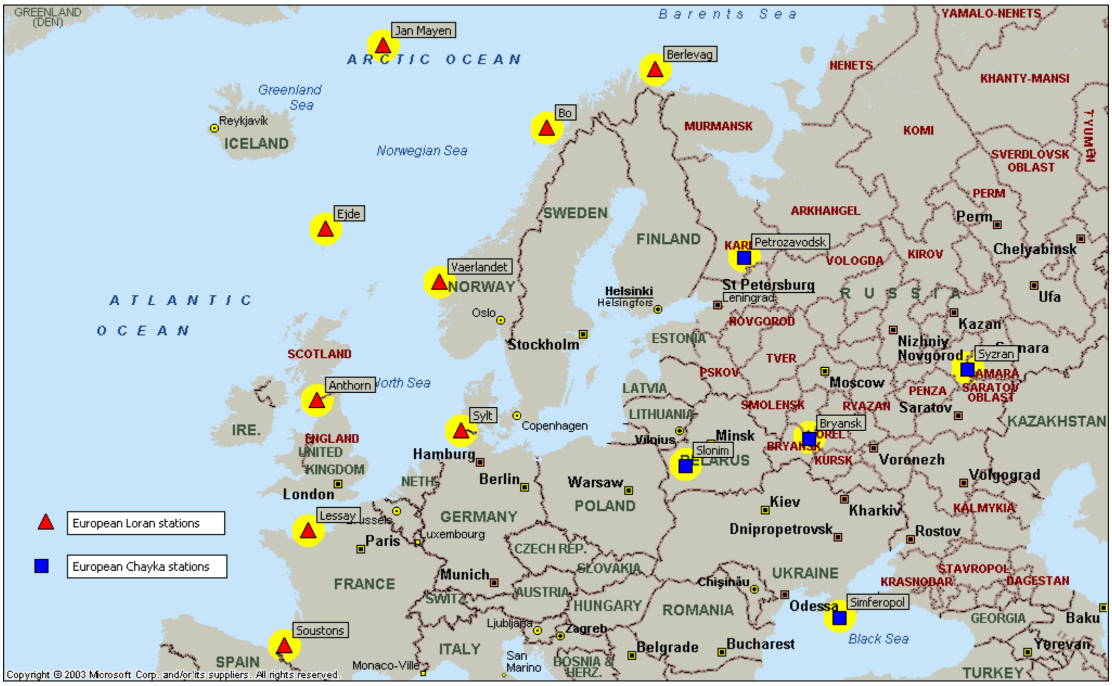
Core Constellations and Complementary Systems

Core constellation providers	Core constellation	Complementary systems
United States of America	GPS	LORAN-C / enhanced LORAN
Russia	GLONASS	LORAN-C / Chayka
Peoples Republic of China	COMPASS / BeiDou II	LORAN-C
Japan	QZSS	LORAN-C
European Union	Galileo	?

4 European implementation strategy

4.1 The European situation

Examination of the existing European LORAN (and Chayka) infrastructure indicates the current potential for coverage of Northern and Central Europe, acknowledging that additional stations would be required to extend the coverage to the South. Conversely, removal of any stations would prejudice this coverage.



To date, the future of eLoran in Europe has been linked with the publication of the European Radio Navigation Plan. The most recent study to define a European Radionavigation Plan (ERNP) made several recommendations that explicitly identified LORAN as a core element of the European radionavigation systems mix, including that:

> *…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.*

Clearly, assessment of the contribution of eLoran to the PNT environment needs to be revisited in the light of the need for PNT to provide a continuously-available input to a range of critical infrastructure.

4.2 European Objectives for eLoran

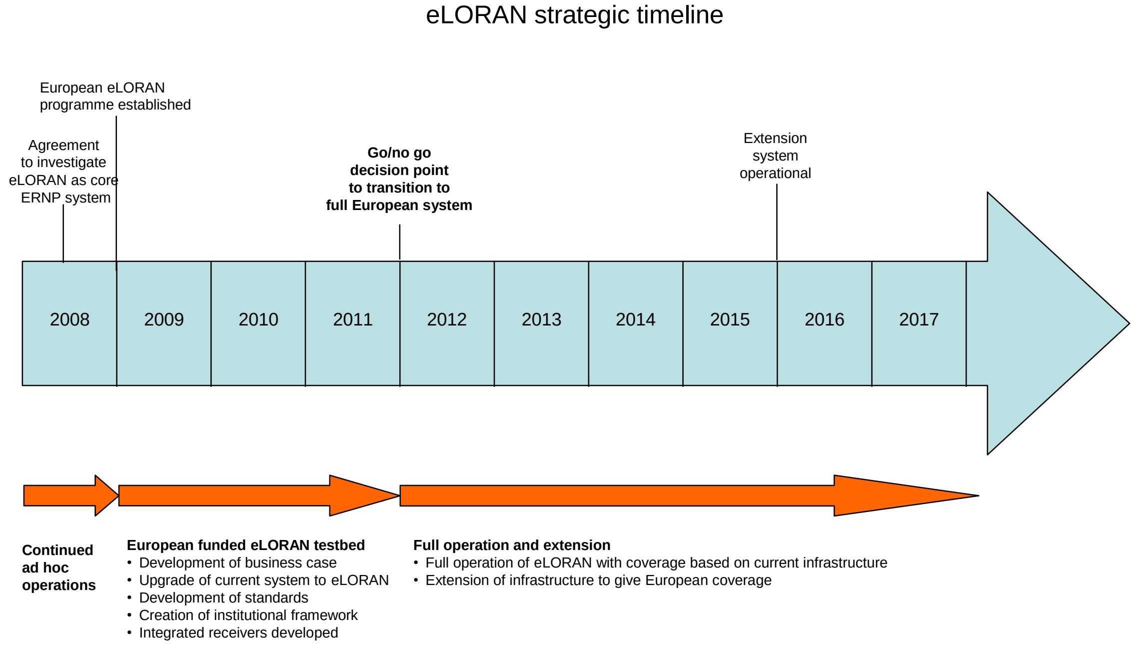
The development and operation of the existing European LORAN infrastructure is currently being undertaken on an *ad-hoc* basis. Securing its future requires a European strategy that places eLoran firmly within the context of an ERNP. Not only will this enable national administrations and service providers to work together towards a common goal, but it will also instil confidence in potential users and equipment manufacturers, facilitating the necessary commitment and investment.

The overall strategy should cover several strands, including:

- supporting the place of eLoran at the core of the European Radionavigation Plan and enabling the European Commission to take the lead on the common development of eLoran;
- establishing the appropriate institutional arrangements, including operational and regulatory structures;
- undertaking the necessary financial analysis to support the overall case for eLoran and to provide individual service providers with the business case that they need;
- technical development, upgrading the current infrastructure to act as an eLoran test-bed to support further tests and standardisation activities; and
- supporting the establishment of the user base by pump-priming the market for affordable receivers.

4.3 Action plan

The baseline action plan and strategic timeline for European eLoran is indicated in the following figure.



The action plan comprises three main phases:

- <u>in the short-term</u>, continued *ad hoc* operations under the current arrangements
- <u>between 2009 and 2011</u>, use of the current infrastructure as a test-bed together with the appropriate financial, feasibility and institutional studies needed to enable a final decision to be made on the future of eLoran in Europe. This phase should be coordinated and funded at the European level
- <u>post-2011</u>, subject to a positive decision, full operation of the European eLoran system under the appropriate institutional, regulatory and financial arrangements as defined in the second phase, together with the extension of the infrastructure to provide the required geographical coverage.

4.4 Finances

Preliminary studies indicate that eLoran is likely to be a very affordable and cost-effective service. The most recent ERNP study concluded that:

> *LORAN-C/EuroFix delivers 22% of the policy benefits for only 4% of the annual total operational cost (€8.5M):*

Since that calculation was carried out, eLoran has been developed as a more effective backup and the range of critical systems in Europe that require such a backup has increased greatly. As an insurance policy, eLoran provides cost effective protection against events and disruptions of GNSS that would lead to a combined cost across the sectors affected of many millions of Euros for a single event.

In order to upgrade the existing Loran-C/Chayka infrastructure to eLoran and to provide the existing European eLoran test-bed, some capital investment is needed. This is estimated to be approximately **€5.5M**. The operating cost per station is estimated to be around **€400k per annum**, implying that the overall annual operating cost of the test-bed would be less that the €8.5M identified in the ERNP.

In addition, a network of reference stations would be required at a capital cost of approximately **€65k** each. The annual operating cost of each reference station is estimated to be **€10k**. The overall cost of the reference station network would, of course, depend on the number of reference stations required.

Therefore, not only does eLoran promise ultimately to be an extremely cost-effective component in the future European PNT environment but also the proposed European programme to run the test-bed and undertake the required studies aimed at a final decision, is relatively affordable.

As it is intended that eLoran will complement and backup GPS and Galileo it is expected that the trend in user equipment will be towards integrated receivers in which eLoran can take over seamlessly to provider robust position, navigation and timing. Such equipment will become increasingly cost effective over time as the market develops. Integrated navigation receivers are expected to be no more expensive in the future than GPS receivers are today.

5 Conclusions

Robust, reliable and high-performance positioning, navigation and timing (PNT) is the lifeblood of a modern society's critical infrastructure. The future prosperity and welfare of Europe is underpinned by this critical infrastructure – but it is dependent upon the Global Positioning System for its PNT.

In the future, GPS and Galileo will rightly form the cornerstone of the future European PNT environment. However, GPS and Galileo share well-known common modes of failure. Playing a supporting role, eLoran will make our PNT foundations robust and resilient and allow PNT users retain their safety, security and economic benefits even when their satellite services are disrupted.

Globally most of the main providers of satellite navigation systems have already recognised the need for diverse and complementary sources of PNT. The US has recently decided to implement eLoran as a backup to GPS; Russia operates its GLONASS satellite navigation system and its version of Loran, Chayka; and China is developing its Compass satellite navigation system but has also deployed LORAN.

In determining its long-term PNT mix Europe needs a mature and rational debate about GNSS vulnerability that recognises both the benefits of having two satellite navigation systems, Galileo and GPS, and the benefits of system diversity based on eLoran.