IDA

INSTITUTE FOR DEFENSE ANALYSES

Independent Assessment Team (IAT) Summary of Initial Findings on eLoran

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January 2009

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INSTITUTE FOR DEFENSE ANALYSES
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eLoran Independent Assessment Team
Executive Summary

Task: In August 2006, Department of Transportation (DOT) Under Secretary for Policy sponsored a task at Institute for Defense Analyses (IDA) to form an Independent Assessment Team (IAT) to review the need for enhanced Loran (eLoran). The sponsor also invited the Department of Homeland Security (DHS) Deputy Under Secretary for Preparedness to participate as co-sponsor. eLoran is an upgraded and fully modernized version of the Loran-C system (see charts 7 and 20 in this report).

The IAT assessed prior studies; conducted detailed interviews with researchers from those studies, agency representatives, other stakeholders, user groups, and international partners; and undertook a "deep dive" into eLoran financial data. Based on the foregoing data collection and its independent assessment of national needs, *the IAT unanimously found and recommended* to the sponsor and co-sponsor on 13 December 2006 *that eLoran be completed and retained as the national backup system* for critical safety of life, national and economic security, and quality of life applications currently reliant on position, time, and/or frequency from GPS.

Report: The sponsor and co-sponsor accepted the IAT conclusions and recommendations and directed that the IAT report (attached 11-chart chart briefing, with 27 backup charts) be given to senior officials throughout all cabinet departments and stakeholder groups (see Appendix A). The final report was the briefing given to the DOT Extended Position-Navigation Executive Committee (consisting of senior representatives of all departments and agencies) and to the DHS Geospatial and Position-Navigation-Timing (PNT) Executive Committee on 20 March 2007.

eLoran Decision: Based on the IAT report, DOT and DHS jointly recommended to the National Space-Based PNT Executive Committee (NPEC) on 28 March 2007 that eLoran be the national backup for GPS. The policy decision, eLoran as national backup, was reached at that NPEC meeting, with implementation assigned to DOT and DHS. The formal announcement was made in a press release by DHS on 8 February 2008 (Appendix B).

IAT Conclusions and Major Recommendation (see report charts 4, 10, 37, and 38)**:**

- Reasonable assurance of national PNT availability is prudent and responsible policy, needed for ubiquitous, *critical safety of life and national and economic security*, as well as quality of life, applications dependent upon GPS-based PNT.
- eLoran is the *only* cost-effective backup for national needs; it is completely interoperable with and independent of GPS, with different propagation and failure mechanisms, plus significantly *superior robustness* to radio frequency interference and jamming. It is a *seamless backup*, and its use *will deter threats* to US national and economic security by disrupting (jamming) GPS reception.
- The US Government policy decision is needed to motivate users to equip and to demonstrate continued leadership internationally.

Thus, the IAT *unanimously recommends* that the U.S. Government complete the eLoran upgrade and commit to *eLoran as the national backup* to GPS for 20 years.

Alternatives Considered: IAT reviewed all prior studies and discussed backup needs with stakeholder groups; each study had been undertaken by an individual agency, transportation mode, or user group. All studies thus considered backup systems only from a single use-specific perspective. After reviewing all prior studies and conducting detailed interviews, the *IAT found that eLoran was the only system which could provide position, navigation, time, and frequency backup capability for all current and potential needs.* Alternatives examined included the following (see report charts 5 and 16-19):

- VOR, DME, ILS: legacy en route and approach aviation systems, applicable only to aviation users.
- Buoys, lighthouses, and State-licensed pilots: legacy maritime systems for port entry and approach; applicable only to maritime users and only in the port environment.
- Local reference frequency standards or oscillators: Time and frequency users' local backups; generally in cellular phone base stations, network nodes, etc. Useful for a few seconds to hours, depending on quality, design, and maintenance; data showed little industry standardization and often poor performance.
- Just-in-time delivery and inventory-in-motion tracking: no identified backup.
- Other transportation modes: limited (generally untested) procedural backup in some cases and no indentified backup in others.
- eLoran: Full position (2-dimensional) and time and frequency backup, adequate for maritime accuracy, aviation integrity, and time and frequency "Stratum 1" needs (collectively, the most demanding requirements), as well as for all other identified and future needs.

Status: eLoran upgrades of existing infrastructure are about 70% complete, funded by Congressional appropriations totaling $159M during FY1997-2006. The most costly upgrades are to the transmitters; all 18 CONUS transmitters and two of six in Alaska have been upgraded to eLoran, which enable immediate staffing reductions (and significant operations and maintenance (O&M) savings). Remaining eLoran work (30% not yet completed) includes completing Alaskan upgrades, adding new unstaffed differential monitors and upgraded time transfer systems, as well as implementing four additional transmitters recommended in CONUS.

Costs: In November 2006, the IAT conducted a "deep dive" into costs. Data were collected from USCG, FAA, and other US Government sources, and checked against data from potential commercial operators and from European countries currently operating eLoran. All government data were used at face value (unchallenged); if two agencies' cost categories could not be determined identical, both categories were included (costs added), and if values differed in any given category, the larger value was used. In summary:

- Decommission existing Loran: $146M ($49M CONUS, $97M Alaska)
- eLoran upgrades (less new transmitters): $83M ($51M CONUS, $32M Alaska)
- New eLoran transmitters: $60M (CONUS only)
- O&M at current staffing: $37M/year
    - At reduced staffing: $20M/year
- Deferred infrastructure repairs: $289M ($44M CONUS, $245M Alaska)
    - Average cost over 20-year life: $15M/year ($2M CONUS, $13M Alaska)

Cost Assessment: The IAT assessment of costs is extremely conservative, effectively *a worst case, overbounded estimate of costs*, which IAT believes could be significantly reduced through immediate application of automation, judicious use of contractor support, and other means to avoid costs of major infrastructure repairs. The assessment in brief follows; this summary is reflected on chart 7 of the main report, and in more detail on charts 24-25 of the backup:

- eLoran (including the recommended four new transmitters) costs about half one new GPS on-orbit satellite.
- If offset by decommissioning cost of existing Loran infrastructure, eLoran is free.
- Deferred maintenance can be addressed, in order of need, by O&M savings, and the largest expenses for buildings, runways, fuel depots, etc. might be avoided altogether by moving two Alaskan transmitters.
- *Bottom line & worst case:* eLoran requires existing $37M/year USCG O&M base funds plus $20M/year new funds for 5-8 years to complete all upgrades, new transmitters, and "jump start" deferred maintenance until de-staffing O&M savings fully kick-in.

Global leadership: The world is dependent upon position, navigation, and time and frequency (PNT) from GPS, and increasingly other nations have recognized the vulnerability of GPS. For example, the General Lighthouse Authorities (GLA) of the UK and Ireland (equivalent to USCG for maritime safety) have committed to eLoran as the automatic backup to GPS/DGPS in its e-Navigation concept for maritime safety in crowded waterways. Essential to the global success of eLoran as such a backup, for maritime and virtually all other safety of life, national and economic security, and other critical applications, is continued US leadership and support.

Report: This IDA document consists of an Executive Summary, an 11-chart briefing, with 27 backup charts, and a discussion of subsequent developments as an appendix. The formal IAT report is this chart set, entitled "Independent Assessment Team (IAT) Summary of Initial Findings on eLoran." This was accepted by the sponsor and co-sponsor in December 2006, and at their request, it was formally presented to and fully endorsed by, the DOT Extended POS-NAV and DHS Geospatial-PNT Executive Committees on 20 March 2007 in Washington, DC.

Independent Assessment Team Members: (see chart 12)

- Dr. Bradford Parkinson, Chair
- James Doherty, Executive Director
- John Darrah
- Arnold Donahue
- Dr. Leon Hirsch
- Donald Jewell
- Dr. William Klepczynski
- Dr. Judah Levine
- Kirk Lewis
- Dr. Edwin Stear
- Phillip Ward
- Pamela Rambow, Research Assistant

Independent Assessment Team (IAT)
Summary of Initial Findings on eLoran

As Presented to
DOT & DHS
POS-NAV Executive Committees

on 20 March 2007
Washington DC

Final Report of Initial Phase of IAT
(Aug-Dec 2006)

Charter *(August 2006)*

- **Conduct independent assessment of Loran**
  - ***Assemble team of experts* to review and assess continuing need for the current US Loran infrastructure***
  - ***Report findings & recommendations directly to Under Secretary of Transportation for Policy***
- **Assess information from recent studies & working groups' reports***
  - ***Use, for example, LORAPP & LORIPP working group reports; studies by Volpe Center, FAA, USCG, HSI, others***
  - ***Supplement with information from key stakeholders and others* as appropriate***

*Note: IAT membership, materials reviewed, & others consulted listed on backup charts

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Government Decision Options

- **Terminate Loran-C**
  - *Declare end date for operations*
  - *Mothball or decommission infrastructure*
- **Continue status quo***
  - *No stated Government position*
  - *Continue current uncertainty & resulting turmoil*
- **Decide that eLoran is primary GPS backup**
  - *Complete eLoran upgrade*
  - *Establish eLoran as primary backup for ~20 years*

Status quo option means "terminate"
NO DECISION IS A TERMINATE DECISION
Manufacturers and Users will not equip

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IAT Conclusions & Recommendation

- **Reasonable assurance of national PNT availability is prudent & responsible policy**
  - *For critical safety of life & economic security applications*
  - *And for all other "quality of life" applications*
- **eLoran is cost effective backup – *to protect & extend GPS***
  - **for identified critical *(& other GPS-based)* applications**
    - *Interoperable & independent*
    - *Different physical limitations & failure modes*
    - *Seamless operations & GPS threat deterrent*
- **Given US Government support, anticipate users will equip with eLoran as the backup of choice**
  - *International community looking for US leadership*
- ***Recommend* complete eLoran upgrade & commit to operate for 20 years**
  - *Affordable within recent funding history*

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Studies Indicate

- **GPS backup (dissimilar failure modes) needed for critical infrastructures requiring position, time, frequency services**
  - *Vulnerability studies demonstrate impact to critical systems due to local interference or jamming of GPS*
  - *Types of GPS uses & numbers of users increasing dramatically*
  - *Technical studies review capabilities of eLoran to provide backup to GPS when needed – interoperable & independent*
  - *Cost/benefit studies appear to support decision to retain eLoran as a backup service to GPS for a broad range of applications*
- **Government agencies & user groups report adequate, but individual system-by-system, backups to GPS already exist**
  - *Most report either equipment or procedural backups in place*
  - *User trade space is cost of equipping with backup system vs. risk*
  - *Studies (limited scope) conducted dominantly in "stovepipes"– limited to domain or area of interest of one agency or user group*

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Current & Future GPS Vulnerabilities

- **Inherent vulnerabilities in systems using RF spectrum**
  - *Increased due to unique GPS characteristics*
    - *Very low signal power*
    - *Single civil frequency – future mitigated with multiple frequencies*
    - *Simple known signal structure – future mitigated with new signals*
- **Unintentional interference – generally local & short duration**
  - *Radio frequency interference (RFI) & GPS testing activities*
  - *Ionospheric disturbances – exacerbated by solar activities*
- **Spectrum competition from non-radionavigation systems**
- **Intentional interference – could be 100 miles & last days**
  - *Jamming (hackers or terrorists)– denial of use*
  - *Spoofing & its variations – counterfeit signals*
  - *Global military & civil use of GPS encourages "disruption industry"*
    - **Jamming techniques well known & devices available or easily built**
- **Disruption of GPS constellation or ground control segment**
- **Human factors**
  - *Errors, over-reliance, lack of knowledge/training*
  - *Mitigated with planned upgrades to GPS control segment (OCX acquisition)*

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Why eLoran

- eLoran meets needs of identified critical applications – and others
  - *10-20 meter accuracy for harbor entrance*
  - *0.3 nautical mile required navigation performance (RNP 0.3)*
  - *Stratum 1 for time & frequency users – 50 ns time accuracy*
- eLoran is NOT 1958 Loran-C
  - *New infrastructure – solid state transmitters, state-of-the-art time & frequency equipment, uninterruptible power supplies*
  - *New operating concepts – time of transmission, all-in-view signals, message channel with differential corrections, integrity, etc.*
  - *New user equipment - digital, processes eLoran & GPS signals interchangeably, compact H-field antennas to eliminate "p-static"*
- eLoran upgrade & 20 year ops affordability
  - *$159M invested to date – nonrecurring $17-25M/yr*
    - Additional $143M will complete eLoran – 5-8 years at current funding level
  - *Ops & maintenance currently $37M/yr – recurring*
    - Reduce routine O&M costs with eLoran efficiencies – apply savings to identified major maintenance backlog ($289M)
  - *Avoid $146M costs of decommissioning existing Loran-C infrastructure*

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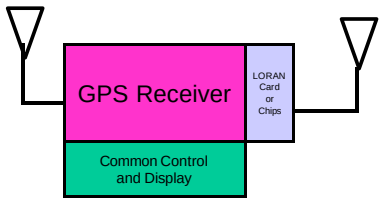
eLoran Is "Seamless" Backup

- Many backups require different skills; e.g., for professional navigators:
  - *Switch to buoys or radar*
  - *Switch to DME or VOR*
- Some traditional skills have been found to atrophy in the GPS era
  - *Operational efficiencies provide fewer opportunities to practice*
  - *Trends expected to continue*



- eLoran nascent user equipment industry
  - *"All up" prototypes exist – limited production possible near term*
  - *Focus is on integrated eLoran & GPS digital receivers*
- Designed as seamless backup, with common operator interface
  - *GPS calibrates eLoran while GPS available*
  - *eLoran extends GPS service into GPS-challenged situations*
  - *Receiver seamlessly switches to eLoran when GPS is lost*
- The implications for safety and ease of use are significant

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National Benefits of eLoran

- Useful in aviation safety of life applications (DOT/FAA)
  - *RNP 0.3, NPA, ADS-B*
  - *But legacy backups (eg, DME, VOR, ILS, etc.) exist*
- Useful in maritime safety of life applications (DHS/USCG)
  - *Harbor entrance & approach*
  - *But legacy backups (eg, buoys, harbor pilots, etc.) exist*
- Useful in timing & frequency applications (DOC?)
  - *Digital cell phone towers & Stratum 1 network switches*
  - *Local oscillators used for backup—varying quality*
- Useful in defense, security, & other applications (DoD, DHS, others)
  - *Extend GPS indoors & under foliage*
  - *Augment GPS in urban & natural canyons*
- Useful as a deterrent to disruption of GPS (DHS, DoD, others)
  - *Enables most applications to continue uninterrupted*
  - *Hence "why bother" to disrupt (jam) GPS*
- Much benefit overall – no one agency to claim "ownership"
  - *Traditionally DOT (i.e., USCG (pre-DHS) & FAA) provided civil "navigation" systems, which also sufficed for other users' needs*

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The Way Ahead

- **Implement IAT recommendations** (13 Dec 2006 briefing)
  - *Decide to retain eLoran for 20 years as primary backup to protect & extend critical (& other) GPS applications*
  - *Fund completion of eLoran*
  - *Reduce eLoran staffing (O&M costs) – start now*
  - *Stimulate eLoran receiver development & equipage*

Closing thoughts

- *Established capability*
- *Well proven*
- *High cost to re-establish*

vs.

- *Low cost to retain*

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Backup

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IAT Members

Dr. Bradford Parkinson – Stanford University – Chair
James Doherty – IDA, former USCG NAVCEN – Exec Director
John Darrah – IDA, former Chief Scientist AF Space Command
Arnold Donahue – NAPA, former OMB
Dr. Leon Hirsch – IDA Research Staff Member
Donald Jewell – IDA, former AF Space Command
Dr. William Klepczynski – IDA, former US Naval Observatory
Dr. Judah Levine – NIST Time Services
L. Kirk Lewis – IDA, Executive Director GPS IRT
Dr. Edwin Stear – IDA, former VP Boeing & AF Chief Scientist
Philip Ward – IDA, former Texas Instruments (GPS receivers)
Pamela Rambow – IDA Research Assistant

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Who We Met with

Government Agencies

- *Department of Transportation (DOT)*
- *Federal Aviation Administration (FAA)*
- *Volpe National Transportation Systems Center (VNTSC)*
- *Department of Homeland Security (DHS)*
- *US Coast Guard (USCG)*
- *Homeland Security Institute (HSI)*
- *US Naval Observatory (USNO)*
- *National Security Space Office (NSSO)*
- *National Institute of Standards & Technology (NIST)*
- *National PNT Coordination Office (NPCO)*

User Groups & Organizations

- *International Loran Association (ILA)*
- *Aircraft Owners & Pilots Association (AOPA)*
- *National Boating Federation (NBF)*
- *American Pilots Association (APA)*

User Equipment Industry

- *Cross Rate Technology*
- *Megapulse*
- *Peterson Integrated Geopositioning*
- *Rockwell Collins*
- *Symmetricom*
- *Timing Solutions Corporation*

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Studies Reviewed (Principle Investigators)

- *GPS Vulnerability (VNTSC)*
- *Timing (HSI, NIST, USNO)*
- *PNT Architecture (NSSO)*
- *eLoran Costs & Benefits (USCG, FAA, VNTSC, Megapulse, Trinity House)*
- *Loran Integrity Performance Panel research & findings (LORIPP)*
- *Loran Accuracy Performance Panel research & findings (LORAPP)*
- *eLoran Characteristics (FAA, USCG, Stanford University, Peterson Integrated Geopositioning)*
- *Aviation Backup Requirements (FAA, Aviation Mgmt Associates)*
- *Aviation Certification Issues (FAA)*
- *Aviation eLoran Performance (FAA)*
- *Maritime Backup Requirements (former TASC/Litton/Northrop Grumman)*
- *Maritime eNavigation (Trinity House & University of Wales)*
- *Interference Detection & Mitigation (IDM) Plan (DHS, USCG)*
- *eLoran Performance Data (Ohio University, Stanford University, Peterson Integrated Geopositioning)*
- *Location-Based Security (Logan Scott Associates, Stanford University)*
- *eLoran as Time & Frequency System (Timing Solutions Corporation)*

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IAT Schedule

- Mid-Aug 2006 — IAT begins
  - *Establish membership & select chair*
  - *Collect read-ahead materials & provide to members*
  - *Develop data collection plan (meetings & briefers)*
- 19-20 Sep 2006 — First meeting – IDA
  - *Focus on vulnerability study, user requirements, & other major studies*
- 10-11 Oct 2006 — Second meeting – IDA
  - *Meet with DOT sponsor & invited DHS co-sponsor*
  - *Focus on other studies plus international, environmental, other issues*
- 1-2 Nov 2006 — Final meeting – Stanford
  - *Focus on user equipment – availability, cost, market research, etc.*
  - *Review need for standards & other equipage issues*
- 6 Nov-12 Dec 2006
  - *Detailed eLoran cost review*
- 13 Dec 2006 — Initial report – DOT HQ
  - *Chair & Executive Director*
  - *DOT Under Secretary for Policy, DHS Deputy Under Secretary for Preparedness, & USCG Assistant Commandant for Prevention*

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Key Questions

- To what degree, & in what way, is GPS vulnerable to persistent outages or local transient discontinuities?
- What are the impacts of such events for safety-of-life, economic disruption, or inconvenience?
- What techniques or alternatives are available as to ameliorate such situations?
- In what time frame & at what costs (& to whom) could such methods be implemented?
- To what degree would we expect the affected users to take advantage of these methods?
  - *What is the proper Government role?*
- What course of action is most reasonable for DOT?

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Vulnerabilities and Backups

	Major Vulnerability	Best Mitigations
GPS System	**G1. Satellite Clock Failure** (e.g. SVN23 1 Jan 2004)	**Addl. Satellites, WAAS, RAIM** (30+X GPS, Galileo SBAS)
	G2. Poor Signal Quality (e.g. Evil Waveforms)	**Addl. Satellites & Signals** WAAS, RAIM (30+X GPS, Galileo SBAS)
	G3. Satellite Design Flaws (e.g. Block IIR ranging code interruptions)	**Multiple Ranging Signals** (WAAS warning + GPS, Galileo Addl. signals)
	G4. Control System Failure (Sabotage or ?)	**Use Differential Corrections** (WAAS, EGNOS, NDGPS etc.)
Signal	**S1. Intentional interference** (e.g. hackers or terrorists)	**Alt. Freq. & or Dissimilar system** (e.g. GPS L5, VOR/DME, or eLoran)
	S2. Unintentional interference (e.g. Moss Landing)	**Alt. Freq. & or Dissimilar system** (e.g. GPS L5, VOR/DME, or eLoran)
	S3. Ionospheric effects (e.g. scintillation at high lat. or equator)	**System with dissimilar Frequency** (e.g. eLoran)
Receiver or User	**R1. Receiver malfunction** (e.g. Royal Majesty, 1995)	**Redundant GPS receivers**
	R2. Signal occultation (e.g. Urban canyons)	**More SVs &/or Dissimilar system** (e.g.Galileo, SBAS, or eLoran)

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Backup Alternatives to GPS

GPS needs dissimilar, complementary, multi-modal, & independent source of GPtS & PNT

Service	PNT	Multi-Modal	Independent of GPS		
			System	Signal	User
Galileo	./	./	./	x	x
eLoran	./(no 3D)	./	./	./	./
DGPS	x	./	x	./	x
SBAS	x . /	./	x . /	x	x
Radar, VOR/DME, ILS	x	x	./	./	./

eLoran is frequency & signal diverse as well as much more powerful (virtually unjammable)

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If not eLoran – Current Backup Plans

Mode	Applications	Backup
Aviation	• **Precision Approach** • **Non-Precision Approach**	**Traditional Ground-Based Navigation, Procedures**
Maritime	• **Harbor & Harbor Approach** • **Constricted Waterway**	**Conventional Navigation Methods**
Land	• **Tracking Radioactive Items** • **Collision Notification**	**Conventional Procedures, Dead-Reckoning, etc.**
Positioning	• **Survey & Geodesy**	**Optical and Inertial Systems**
Timing	• **Communications, Power Grids, etc.**	**Loran-C, WAAS, Clocks**

Source: National Space-Based PNT Coordination Office

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eLoran (upgrades well demonstrated)

- **Upgrade of Loran infrastructure & operations concept**
  - *Signal in space updated for digital use (GPS-like, digital user equipment)*
  - *Time of arrival (TOA) or "pseudo-range" navigation (same as GPS)*
  - *New Messaging channel increases position & time accuracy using differential Loran (About 10-20m within 20 miles from monitor)*
  - *Backward compatible for legacy users*
- **"All-in-view" navigation**
  - *All masters & secondary transmitters directly synchronized (<20ns) enabling "cross chain" or "all-in-view" navigation*
  - *User stores or calculates Additional Secondary-Phase Factor (ASF) corrections for improved accuracy*
  - *All received signals useable (improves geometry/accuracy, extends coverage)*
- **eLoran transmitter stations**
  - *Solid state transmitters – "soft fail" devices*
  - *Emergency generators & full transmitter battery – no "momentaries"*
  - *Ensembled atomic clocks at each transmitter (compatible with GPS, yet independent of GPS)*

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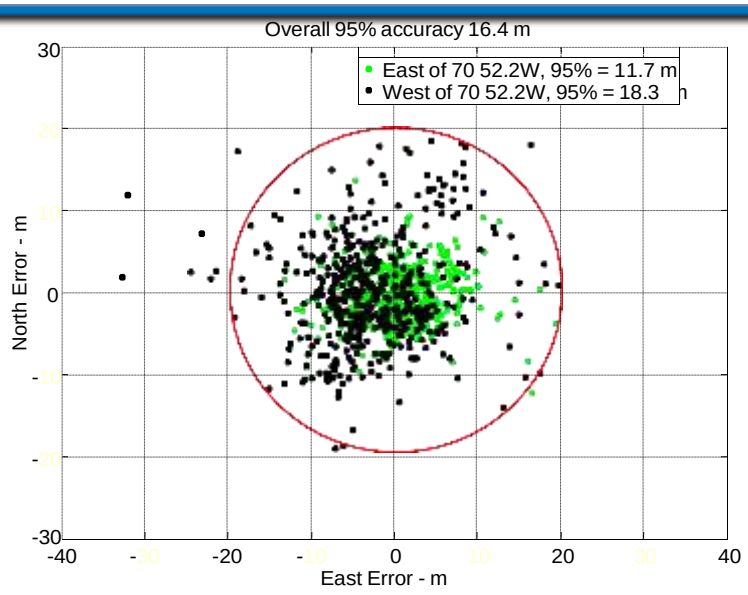
Boston Harbor – eLoran Accuracy



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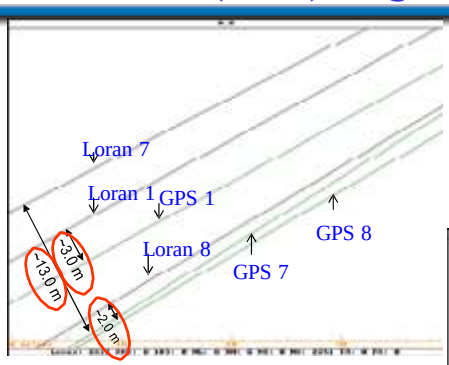
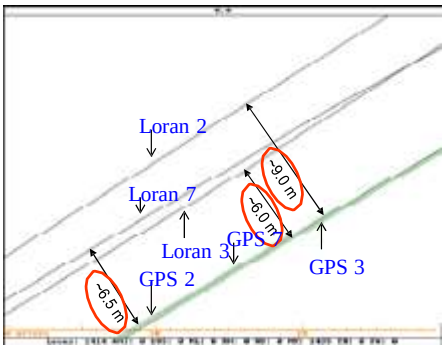
Non-Precision Approach (NPA) Flight Test Results





NPA Requirement: 307 m

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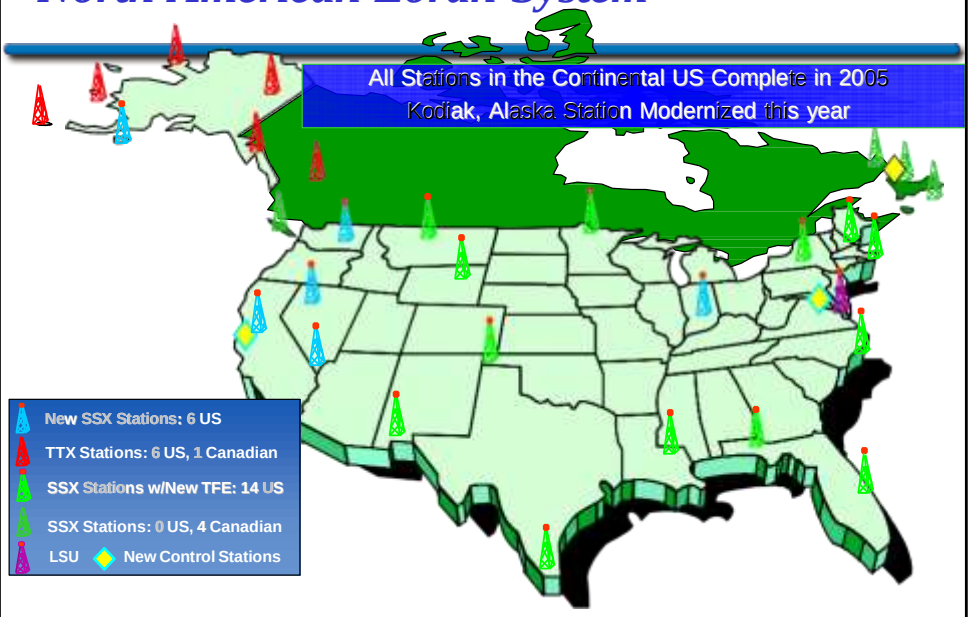
North American Loran System



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eLoran Costs

- **Nonrecurring eLoran funds to date (provided to FAA)**
  - *FY 1997-2006: $159M (FY 2001-2006: $17M - $25M per year)*
  - *Completed existing transmitters, building modifications, etc. in CONUS & began in Alaska (first of six transmitters completed)*
- **Decommissioning costs of current infrastructure**
  - *USCG estimate $146M (~$97M of this in Alaska)*
- **Operations & maintenance (recurring funds – currently in USCG base)**
  - *Currently $37M per year*
  - *eLoran estimate ~$15M per year*
- **Personnel impact of eLoran**
  - *Currently 283 USCG personnel*
  - *Reduce to less than 41 government plus 55 contractor*

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IAT Assessment of Costs

- **Based primarily on USCG reported costs – overbound of costs**
- **For eLoran in CONUS**
  - *eLoran upgrades remaining* — *$ 51M (nonrecurring)*
  - *eLoran expansion (4 xmtrs @ $15M)* — *$ 60M (nonrecurring)*
  - *Major maintenance (backlog & deferred)* — *$ 44M ($2.2M/yr for 20 yrs)*
- **Alaska**
  - *eLoran upgrades remaining* — *$ 32M (nonrecurring)*
  - *Major maintenance (backlog & deferred)* — *$245M ($12.25M/yr for 20 yrs)*
- **Initial assessment**
  - *Provide additional nonrecurring funds – $143M (over 5-8 years)*
    - *$111M to complete eLoran in CONUS*
    - *$32M to complete eLoran in Alaska*
  - *Reduce current O&M ($37M/yr) thru eLoran economies*
    - *Begin with available economies available in CONUS today*
    - *Apply savings to major maintenance*
- **Full eLoran is achievable within current funding**
  - *$20-25M/yr acquisition funds (currently in FAA) for 5-8 years*
  - *$37M/yr (currently in USCG) for life of system*

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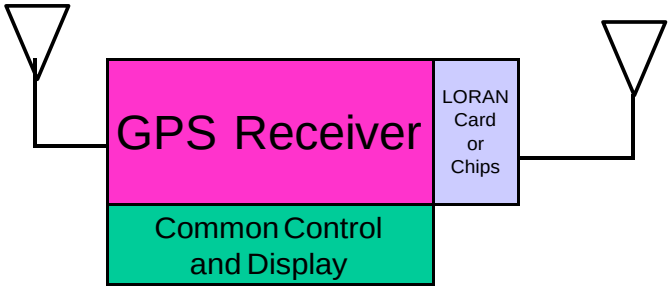
Discussion of Loran User Equipment

- **Manufacturers**
  - *Have demonstrated "all-up" prototypes*
  - *Incremental manufacturing cost <$300 in volume*



- **Stand alone Cost <$1000 in volume**

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Discussion of User Equipment

- Impact of GPS on Loran
  - *User equipment industry shifted from Loran-C to GPS by early 1990s*
  - *Loran-C receivers are old analog designs & virtually impossible to find (even used)*
- Small niche eLoran industry developed recently
  - *Based on Congressional eLoran funding (beginning FY1997 & continuing)*
  - *Universities, individual researchers, & 4-6 small/medium companies interested*
- Essential technical developments needed for eLoran user equipment
  - *Digital receivers – virtually identical signal processing for eLoran & GPS signals*
    - Enables integrated GPS-eLoran receiver sets
    - Stores & applies local databases (eg, ASF correction tables)
    - Processes Loran data messages
  - *H-field antennas – eliminates former Loran-C aviation "p-static" problems*
- Several (at least 3) integrated GPS-eLoran receiver products
  - *Available within a few months in up to10K quantities for $700-1000 each*
  - *Plans to reduce unit price within a year to <$100 if approaching quantities 100K assured*
  - *None yet certified for aviation (RNP 0.3, NPA) –universities & researchers have tested & continue to test various models in flight situations*

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Discussion of User Equipment

- Market research
  - *At least two firms report robust potential markets for combined GPS-eLoran user equipment – unit cost ranging $400-$7000*
  - *Major selling point reported is reliability (to continue operation if GPS is interrupted and to deter intentional disruption of GPS)*
  - *Additionally to enhance GPS (for example, inside buildings or with additional capabilities, such as authentication messages for assured location-based services & security)*
- User categories & market size (# potential units)
  - *Maritime (GPS backup) – 750K*
  - *Military & first responder (GPS backup & indoors) – 32K*
  - *Fleet management (GPS backup) – 1000K*
  - *Timing (cell towers, TV, cable—GPS backup & assured location based services) – 27K*
  - *Network servers (indoors & GPS backup) – 1000s/yr.*
- One researcher estimates market value
  - *$1.1B today*
  - *Growing to $2B by 2010*

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Would Users Equip with eLORAN?

- **Necessary conditions**
  - ***USG commitment (at least 15 years)***
  - ***UE available at small incremental costs***
- **Motivation**
  - ***Rules and regulations***
  - ***Perceptions of threat***

IAT believes speed of equipage (after necessary conditions met)
Will be driven by future events not now predictable

The USG should assume responsibility to have an affordable backup to GPS in place

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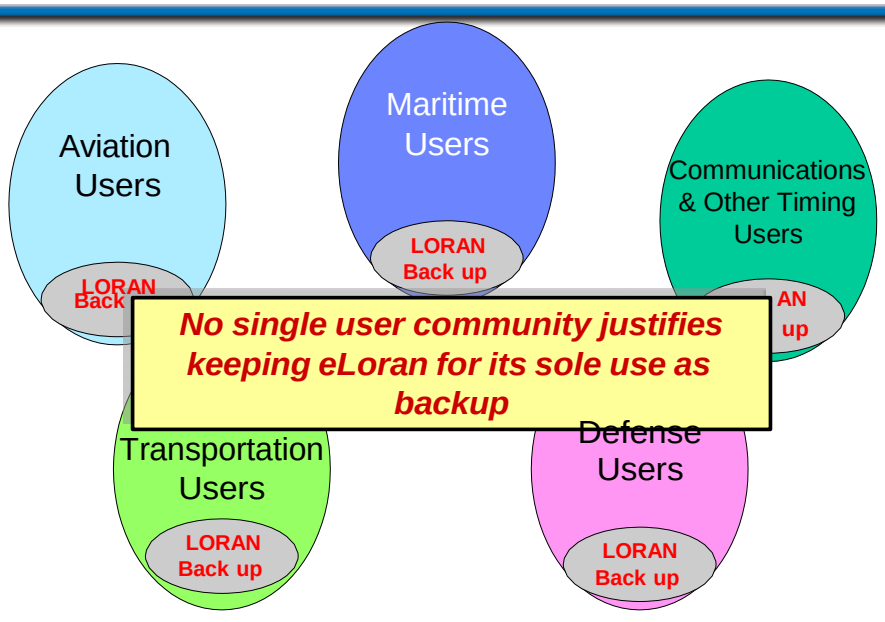
Current Situation – GPS is Primary



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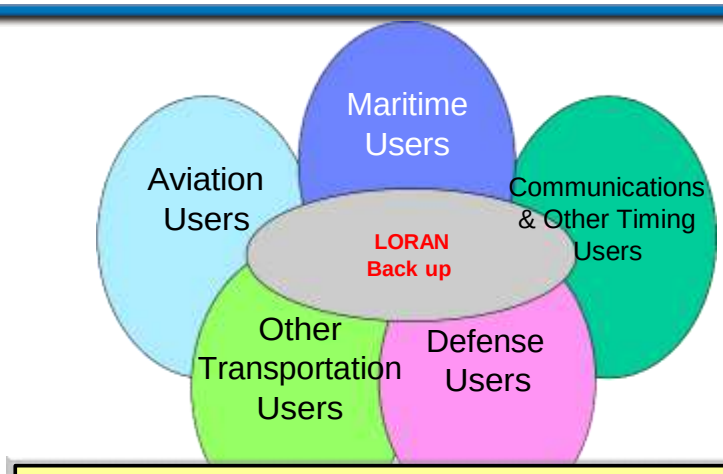
Combined Community Need – GPS Primary



But an ensemble of users needing backup could support continuing eLoran

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Summary of Findings (1)

- **eLoran is Independent of, but compatible with, GPS**
  - ***Source of both position & time information***
- **eLoran is robustly engineered system**
  - ***Ensembled frequency standards at each transmitter***
  - ***Soft-fail transmitter & uninterruptible power supply***
- **Most users will not *now* voluntarily equip with a "backup" system**
  - ***Interference threats could rapidly change perception***
  - ***Regulation and/or incentive programs would speed more widespread use***

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Summary of Findings (2)

- **eLoran is not yet completed**
  - *Transmitters in CONUS completed*
  - *Transmitters in Alaska & Canada need eLoran upgrade*
  - *Differential Loran sites needed, ports & other locations*
    - For harbor accuracy
    - For time accuracy
  - *Additional transmitters needed*
    - For maritime coverage in southern Florida/Caribbean & southern California
    - For aviation integrity in Midwest
- **eLoran costs must be reduced if system persists**
  - *Reduce/eliminate transmitter staffing*
  - *Relocate transmitters to more accessible sites in Alaska*

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Summary of Findings (3)

- **There is no eLoran user equipment**
  - *Legacy Loran (Loran-C) receivers no longer available*
  - *Loran-C receivers will not provide eLoran benefits*
- **Prototype eLoran user equipment exists**
  - *Several companies pursuing integrated GPS & eLoran receivers*
  - *Cost <$1000 in 10K unit quantities; anticipate reduce to <$100 in 100K quantities*

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Summary of Findings (4)

- **Principal threat to GPS is deliberate or inadvertent jamming of the GPS signals**
  - *This would be local and could cause significant disruptions in GPS service. Particularly:*
    - Timing
    - Harbor Entrance and Approach (particularly congested harbors)
    - Aircraft Non Precision Approach
  - *Government Agencies generally have some form of backup*
    - Economic costs of such disruptions could still be substantial
  - *Some risk to safety of life, but it is probably low*
- **Enhanced and modernized eLoran has been well-demonstrated, could quickly be operational** (less than 3 years)
  - *The Europeans have continued to upgrade their LORAN and are already operating "unmanned"*
  - *Full Investment cost < $250M more than cost of total LORAN deactivation (~$143M)*
  - *Operating costs (as demonstrated by the Europeans) ~$15M per year, requires changes in USCG operating policies*

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Summary of Findings (5)

- **eLoran is capable of being a backup for most GPS-enabled critical applications**
  - *Important Missions*
    - **Aviation – RNP 0.3 & NPA**
    - **Maritime – harbor entrance & approach**
    - **Time & frequency – 50 ns & stratum 1**
  - *As an addition to a GPS receiver, the manufacturing cost should be less than $300*
- **As a backup to GPS**
  - *A good backup such as eLORAN may be an effective deterrent to hackers or terrorists deliberately interfering with the signals GPS*

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Conclusions

- **Reasonable assurance of national PNT availability is a prudent and responsible policy**
- **Fully upgraded eLORAN is a very cost effective backup to GPS**
  - ***Particularly useful for Timing, NPA and HEA***
  - ***Incremental net investment of ~$250M***
  - ***Also has some deterrent value***
- **With USG support for the system, users expected to gradually add the eLORAN backup**
  - ***It wll become an economically appealing insurance policy (Δ cost for mfr. ~$300)***

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Unanimous Recommendations of IAT

- **Retain eLoran as primary backup for critical GPS applications**
  - ***Fund completion of eLoran***
  - ***Commit to 20 years***
- **Develop funding plan for completion of eLoran**
  - ***Add differential sites for maritime & timing needs***
  - ***Review alternatives for reducing costs in Alaska***
  - ***Add transmitters for maritime & aviation use in CONUS***
- **Convert to unmanned model (as in Europe)**
  - ***Goal $15M/year operating costs***
- **Stimulate receiver development & equipage**
  - ***Integrate eLoran as backup within GPS receivers***
  - ***Reduce costs through mass production***
  - ***Consider regulation or incentives for equipage in key applications***

eLoran Independent Assessment Team
Appendix A
Subsequent Developments December 2006 – October 2008

Policy Decision: Following acceptance of the report and approval of its recommendations by the DOT sponsor and DHS co-sponsor, they tasked the IAT to take its report to senior leaders throughout the US Government and to other stakeholders. The final "pre-decisional" IAT briefings were given in March 2007 to the DoD Position Navigation Time Senior Warfighter Forum (PNT SWarF), introduced by the senior DHS/USCG representative (Assistant Commandant Marine Safety); to the Extended (all civil agencies) DOT Position Navigation Executive Committee, introduced by the DOT Under Secretary and DHS Deputy Under Secretary; and to the DHS Geospatial PNT Executive Committee, also introduced by the DOT Under Secretary and DHS Deputy Under Secretary. After extensive discussion in all three forums, the PNT SWarF acknowledged the need for eLoran as the national backup for civil users, and both DOT Extended and DHS EXCOMs unanimously approved eLoran as the national backup for all civil users. Subsequently, DOT and DHS jointly recommended to the National PNT Executive Committee on 28 March 2007 that eLoran be the national GPS backup; this recommendation was approved at that meeting and DOT and DHS were directed to coordinate implementation.

Follow-on Briefings: At the request of the sponsor and co-sponsor, the IAT report remains in briefing format. The briefing includes eleven charts, plus 27 more in backup. From December 2006 through October 2007, the report (this chart set) was fully briefed to senior officials throughout the US government and elsewhere. In each case, there were detailed questions, and all admitted the brief helped them understand the national need for GPA backup and that the eLoran was only alternative meeting the technical requirements at reasonable cost. Paper or electronic copies of the charts, including backups, were given to all those briefed.

Officials who also received the IAT report include the following principals, plus key subordinates and senior staff:

- Deputy Secretary of Transportation (DOT)
- Deputy Secretary of Homeland Security (DHS)
- Assistant Secretary Defense for Networks and Information Integration (ASD/NII)
- Under Secretary of Defense for Intelligence (USD/I)
- Deputy Chief Information Officer for Director of National Intelligence (DNI)
- Deputy Administrator, Federal Aviation Administration (FAA)
- Deputy Administrator, National Geospatial-Intelligence Agency (NGA)
- Assistant Commandant for Marine Safety, US Coast Guard (USCG)
- DOT, DHS, FAA, USCG examiners, Office of Management & Budget (OMB)
- Maritime Security Advisor, National Security Council (NSC)
- National PNT Coordination Office
- National Security Space Office (NSSO, National PNT Architecture)

Additionally, the sponsor and co-sponsor also requested that several outside organizations be briefed; key among these were the following:

- Industry Executive Subcommittee (IES) of the National Security Telecommunications Advisory Committee (NSTAC); this was in response to a request from the Homeland Security Advisor
- National PNT Advisory Committee
- Cross government group (i.e., interagency group) of the UK government in London; this was a request from the Ministry for Transport (MfT)

eLoran User Equipment: An important question for almost all those who received the IAT report was about the availability and estimated cost of user equipment. Fortunately, the IAT had collected data from the nascent eLoran user equipment industry, and through the industry, substantial market survey information. When told that eLoran receivers would be embedded in GPS receivers for seamless backup, and based on data provided to the IAT, for nominal cost increase, they were satisfied that eLoran would be cost effective "reliable GPS." Example used was usually that of an equipment set for vehicle (truck) tracking and reporting; installed, a GPS-only system was reported to the IAT as costing about $6000, and a GPS with seamless backup eLoran would be about $6500.

San Diego Incident: It is important to note, that shortly after the IAT had completed its deliberations and delivered its report briefing to the sponsor and co-sponsor, there was an interference incident that confirmed the need for eLoran as a seamless national backup. For about 3 hours one afternoon, Navy technicians in San Diego turned on a test signal which interfered with GPS reception; once the technicians discovered their error, they turned off the interfering signal. The interfering signal affected GPS reception in San Diego harbor and approaches, in the downtown area including the international airport, and throughout the surrounding area for about 10 miles inland and all the way south to the Mexican border.

Although no safety of life accidents occurred, all civil and commercial user categories were affected. The maritime DGPS system and Automated Identification System (AIS) were shut down, commercial, recreational, and Coast Guard vessel operations affected, some aviation users were affected, two cell phone base stations were shut down and upwards of 150 others were degraded, and a first responder pager network was shut down. It is safe to assume that had it been possible to get reports, delivery vehicles which navigate, report their position, and keep track of pick ups and deliveries by GPS coordinates would also have demonstrated that "just-in-time" deliveries and "inventory-in-motion" tracking were disrupted.

The GPS disruption not only caused loss of position or navigation data for ships, boats, aircraft, trucks, and automobiles. It also disrupted the critical communications systems that rely on GPS to condition a local reference frequency source or provide stable timing. One unique demonstration of the seriousness of the impact was disruption of the USCG Automatic Identification System (AIS). AIS is a self-organizing, time-division multiplexed communications network used for vessel-vessel collision avoidance and port safety, port security, and vessel traffic management by the Coast Guard. It requires time-

tagging based on GPS Time to assign time slots to messages sent and received by all participants in the network. Without GPS, it can not self-organize or remain in synchronization. This demonstrated loss of position and navigation information among the maritime participants, and also inability to communicate with each other through loss of both time and frequency synchronization in the network.

In other words, this was a very serious incident.

Although the technicians self-corrected, had they not, USCG, FAA, FCC, and others applied an analysis to determine likely location of the interference source. This process took approximately 36 hours, and localized the jammer with about a 1 mile uncertainty. Unfortunately, the analysis indicated it was on Coronado Island, not the mainland—the next step was to knock on doors, so it would have taken quite some time to go from Coronado over the bridge to the mainland to find the interference source.

Had eLoran been implemented, however, all of the adversely impacted users above would have operated seamlessly through the incident. The interference source had been stationary and continuously on, i.e., it was not being deceptive; imagine if someone were deliberately deceptive, with multiple jammers, moving randomly, and turning on and off at random intervals. eLoran would, however, deter someone from such extensive efforts.

Federal Register Notice: On January 8, 2007, the Secretaries of DOT and DHS requested public input on the need for Loran-C (current system) and eLoran (proposed) in a Federal Register Notice. The response period was about a month, with several public hearings, and the response was quite large—about 1000 individual responses, all but a handful in favor of retaining Loran. Respondents included aviation, maritime, and communications users, including both private citizens and corporate officials.

Implementation Considerations: Since World War II, or for the entire history of Loran (Loran-A, Loran-C, and now eLoran), USCG has been the developer and operator of Loran in the US (and until 1995 throughout the world). Since 1997, Congress has directed funds to FAA for eLoran upgrade. In 2003, with the creation of DHS, USCG moved from DOT to DHS, taking oversight of eLoran out of one department (DOT) and moving into the interagency.

Funding any program or system through the interagency process is difficult. For example, GPS is a ubiquitous military and civil "utility." The current process is to assign GPS to an executive agent, the best being USAF in DoD, to assured continued funding of improvements and reliable O&M. The same is probably needed for eLoran. The choices based on funding history are USCG in DHS or FAA in DOT; a subsequent draft assessment by the IAT showed that the combination of FAA for upgrade and USCG for O&M, though awkward, appeared to be workable. However, if not a combination, leaving all in USCG would be next best, followed by FAA. Almost no other agency has the necessary background or experience to provide what is first and foremost a "safety of life" navigation system, which also provide full interagency position, navigation, time, and frequency backup for critical applications based on GPS.

Current Status – October 2008: Policy decision has been made (March 2007) and announced in February 2008. Announcement was accompanied by implementation plan—move eLoran from USCG to DHS NPPD (National Communications System) effective with start of FY2009. In July 2008, DHS and USCG appropriations committee language indicated Congress did not approve the implementation plan and directed that eLoran remain in USCG. Since this was appropriations language, it is effectively a "one year" disapproval of the implementation plan. However, one should probably consider this a bellwether indication—Congress believes that eLoran should remain in USCG.

International and Other Considerations: The General Lighthouse Authorities (GLA) of the UK and Ireland (equivalent to USCG for maritime safety) requested the IAT briefing given above to the UK cross government group. The reason is that the GLAs have committed to e-Navigation for maritime safety, using GPS/DGPS as primary input, eLoran as secondary or backup, and electronic charting.

Based on the GLA initiative, the International Association of Lighthouse Authorities (IALA) has undertaken to define international standards for e-Navigation, and as needed for eLoran. In Europe, France, Germany, Denmark, Netherlands, and Norway are cooperating in this endeavor. Additionally, Russia, Italy, Saudi Arabia, Japan, Korea, and China, all of which operate Loran systems, continue to monitor these developments. Informal assessments are that if US joins the mix effectively, eLoran will become the maritime backup of choice.

Currently, the Radio Technical Commission for Maritime Services (RTCM) has initiated a process to identify signal in space and receiver performance standards for eLoran in the maritime environment. It is likely that the Radio Technical Commission for Aeronautics (RTCA) would engage in a similar effort for aviation users. These national efforts in the US would provide input to the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO) to broaden these standards globally.

Finally, for decades, "navigation" requirements have been the pacing requirements for "navigation systems" such as GPS and eLoran. Time and frequency users were delighted to make use of these systems for their needs. However, in the global search for bandwidth for wireless applications, cell phones, location based services, etc., more and more the needs for time accuracy and frequency precision are becoming the pacing requirements, with the result that navigation users would also be delighted. In addition to this change, there is another fundamental shift in the user community for "navigation" systems. That is, use of these systems is no longer limited to the small professional community of military, maritime, and aviation navigators and engineers and scientists in the time and frequency laboratories. These systems are ubiquitous and being used by everyone in ways never before imagined.

eLoran Independent Assessment Team
Appendix B
Policy Decision Announcement

U.S. Department of Homeland Security

February 7, 2008
Contact: (202) 282-8010

STATEMENT FROM DHS PRESS SECRETARY LAURA KEEHHNER ON THE ADOPTION OF NATIONAL BACKUP SYSTEM TO GPS

Today the U.S. Department of Homeland Security will begin implementing an independent national positioning, navigation and timing system that complements the Global Positioning System (GPS) in the event of an outage or disruption in service.

The enhanced Loran, or eLoran, system will be a land-based, independent system and will mitigate any safety, security, or economic effects of a GPS outage or disruption. GPS is a satellite-based system widely used for positioning, navigation, and timing. The eLoran system will be an enhanced and modernized version of Loran-C, long used by mariners and aviators and originally developed for civil marine use in coastal areas.

In addition to providing backup coverage, the signal strength and penetration capability of eLoran will provide support to first responders and other operators in environments that GPS cannot support, such as under heavy foliage, in some underground areas, and in dense high-rise structures. The system will use modernized transmitting stations and an upgraded network.

The Institute for Defense Analyses is a non-profit corporation that administers three federally funded research and development centers to provide objective analyses of national security issues, particularly those requiring scientific and technical expertise, and conduct related research on other national challenges.