The eLoran Evaluation and Modernization Program

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Acknowledging the Past
Looking to the Future

Mitchell J. Narins
Program Manager
Federal Aviation Administration
Navigation Services

International Loran Association Conference
Orlando, Florida
16 October 2007
eLoran Program - Logo Collection – Fall 2007
It’s a big world and ... ... Loran still serves half of it!
From Whence We Came - Loran-C 2001

TTX Stations: 11 US, 1 Canadian
SSX Stations: 13 US, 4 Canadian
LSU  Control Stations
Loran-C (according to the FRP)

• A hyperbolic radionavigation system…
  • …operating between 90 kHz and 110 kHz…
  • …that uses a very tall antenna…
  • …that broadcasts primarily a groundwave
  • …at high power…
  • …that provides both lateral position…
  • …and a robust time and frequency standard

• A supplemental system for enroute navigation in the US National Airspace System (NAS)

• A system for maritime navigation in the coastal confluence zone (CCZ)

• A Stratum 1 frequency standard (i.e., 1 x 10^{-11}) that also provides time within 100 ns of UTC (USNO)
Loran-C (according to the FRP)

• Provides:
  • A predicted 2drms accuracy of 0.25 nm (460 m) and a repeatable accuracy of 60-300 ft (18-90 m)*
  • An availability of 99.7% (based on triad operation)*
  • A level of Integrity based on exceeding certain operational parameters measured at the transmitters and at system area monitor sites.
  • Continuity no greater than 99.7% (its availability), but potentially worse depending on receiver characteristics and geometry of the triad being used, and…..

*If this was all that Loran could do, the US would have turned it off!*
2001: ...A Growing Awareness...

- The Global Positioning System (GPS) is a major national and international asset with expanding and evolving uses in precision timing and in positioning-navigation services.

- “There is a growing awareness within the transportation community that the safety and economic risks associated with loss or degradation of the GPS signal have been underestimated ... Public policy must ensure that safety [and economic viability] are maintained in the event of loss of GPS.”*

*“Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System,” Volpe Center, August 29, 2001 – Released September 10, 2001!
GPS Vulnerability – An Accepted Fact

• GPS is vulnerable to unintentional and intentional disruptions covering small to extensive areas, for durations from minutes to days

• Illustrations:
  – 1-5 watt intermittent jammers (confound detection) capable of disrupting the GPS signal are available today to place in harbor and shore areas
  – “Jamfest” testing in White Sands, NM (2005) recorded cell phone disruption within 20-25 min of jamming onset
  – San Diego disruption (Jan 07)

• US public policy already requires that backup systems or procedures be available to mitigate GPS disruptions in critical applications (National Security Presidential Directive 39 Fact Sheet, December 15, 2004)
US Loran-C Policy – 2001

“While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids. With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C chains and the use of digital receivers may support improved accuracy and coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support non precision instrument approach operations.”

– Para 3.2.5 B 1999 US Federal Radionavigation Plan
2002 – FAA Loran Murder Board
LORIPP and LORAPP Formed!

- **Loran Integrity Performance Panel (LORIPP)**
  - Co-Chairs
    - Dr. Per Enge, Stanford University
    - Dr. Ben Peterson, Peterson Integrated Geopositioning
  - Challenge: Determine whether an eLoran system can meet the stringent integrity requirements for non-precision approach in the US National Airspace System
  - Requirement: The probability of the system providing hazardous or misleading information < 1 x 10^{-7} per hour
  - Methodology: Utilize the processes and procedures successfully followed by WAAS
2002 – LORIPP and LORAPP Formed!

• Loran Accuracy Performance Panel (LORAPP)
  – Co-Chairs
    • Dr. Ben Peterson, Peterson Integrated Geopositioning (PIG)
    • CAPT Gordon Weeks, CO, USCG Loran Support Unit
  – Challenge: Determine whether an eLoran system can meet the stringent accuracy requirements for harbor entrance and approach
  – Requirement: The positioning accuracy of the system to be 8 – 20 meters.
Loran- C vs. *eLoran* Metrics
FAA 2002 “Murder Board” Requirements

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Availability</th>
<th>Integrity</th>
<th>Continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em><em>Loran-C Definition of Capability</em> (US FRP)</em>*</td>
<td>0.25 nm (463 m)</td>
<td>0.997</td>
<td>10 second alarm/25 m error</td>
<td>0.997</td>
</tr>
<tr>
<td><strong>FAA NPA (RNP 0.3)</strong> <strong>Requirements</strong></td>
<td>0.16 nm (307 m)</td>
<td><strong>0.999 - 0.9999</strong>(1 x 10⁻⁷)</td>
<td></td>
<td><strong>0.999 - 0.9999 over 150 sec</strong></td>
</tr>
<tr>
<td><strong>US Coast Guard HEA</strong> <strong>Requirements</strong></td>
<td><strong>0.004 - 0.01 nm (8 – 20 m)</strong></td>
<td><strong>0.997 - 0.999</strong></td>
<td>10 second alarm/25 m error (3 x 10⁻⁵)</td>
<td>0.9985 – 0.9997 over 3 hours</td>
</tr>
</tbody>
</table>

* Includes Stratum 1 timing and frequency capability
** Non-Precision Approach Required Navigation Performance
"The evaluation shows that the modernized Loran system could satisfy the current NPA, HEA, and timing/frequency requirements in the 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."
A Real Turning Point was Reached

Celebrate the Achievements!
Remember Loran-C in 2001

TTX Stations: 11 US, 1 Canadian
SSX Stations: 13 US, 4 Canadian
LSU Control Stations
**North American Loran System - 2007**

**St. Paul**

**December 2007!**

*Another Team Success!*

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**New SSX Stations:** 6 US

**TTX Stations:** 4 US, 1 Canadian

**SSX Stations w/New TFE:** 14 US

**SSX Stations:** 0 US, 4 Canadian

**LSU**

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**International Loran Association Conference – Orlando, Florida**

16 October 2007
Why Teamwork Remains a Key Element

U.S. Loran Evaluation and Modernization Program
Cumulative Expenditures
FY 97 - FY 06

Fiscal Year

Dollars (millions)

0 20 40 60 80 100 120 140 160 180

97 98 99 00 01 02 03 04 05 06 07 08
Independent Assessment Team Established

Charter:

• Conduct independent assessment of Loran
  – Assemble team of experts to review and assess continuing need for the current US Loran infrastructure
  – Report findings and recommendations directly to Under Secretary of Transportation for Policy

• Assess information from recent studies and working groups’ reports
  – Use, for example, Loran Accuracy Performance Panel (LORAPP) and Loran Integrity Performance Panel (LORIPP) working group reports; studies by Volpe Center, FAA, USCG, HSI, others
  – Supplement with information from key stakeholders and others as appropriate
2006: Loran Independent Assessment Team

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 and AF Chief Scientist
Philip Ward – IDA, former Texas Instruments (GPS receivers)
Pamela Rambow – IDA Research Assistant
IAT Key Questions

• To what degree, and 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 to ameliorate such situations?
• In what time frame and at what costs (and 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?
IAT Government Decision Options

• **Terminate Loran**
  – Declare end date for operations
  – Mothball or decommission infrastructure (~$150M)

• **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 15-20 years

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*Status quo option means “terminate”

**NO DECISION IS A TERMINATE DECISION**

Manufacturers and Users will not equip
Information Presented to IAT: Backup Alternatives to GPS

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

<table>
<thead>
<tr>
<th>Service</th>
<th>PNT</th>
<th>Multi-Modal</th>
<th>Independent of GPS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>System</td>
</tr>
<tr>
<td>Galileo</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>eLoran</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>DGPS</td>
<td>❌</td>
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<td>SBAS</td>
<td>❌</td>
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<td>❌ ✔</td>
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<tr>
<td>Radar</td>
<td>❌</td>
<td>❌</td>
<td>✔</td>
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</tbody>
</table>

- **eLoran is frequency and signal diverse as well as much more powerful (virtually unjammable)**
No single user community justifies keeping eLoran for its sole use as backup
An ensemble of users needing backup could support continuing eLoran
The IAT Conclusions not yet released;

• **However:**
  
  – **US House of Representatives Department of Homeland Security Appropriations Committee**
    
    - The Committee also understands that in late 2006, DOT convened an Independent Assessment Team, in cooperation with DHS, to complete yet another evaluation of Loran C. The Team concluded that Loran C should be retained and modernized to serve as a long term back up for GPS.

  – **US Senate Department of Homeland Security Appropriations Committee**
    
    - The Committee understands that a group composed of officials from the Departments of Homeland Security and Transportation, and other Federal agencies met earlier this year and unanimously agreed that the United States should maintain the Loran system.
IAT Conclusions – Not Yet Released

• **However:**
  – **DHS Letter to US Senate Authorization Committee** (20 Sept 2007)
    • The Spaced-Based Positioning, Navigation and Timing (PNT) Executive Committee, co-chaired by the Deputy Secretaries of the Department of Defense (DOD) and the Department of Transportation (DOT), concurred with a joint Department of Homeland Security (DHS)-DOT policy recommendation to pursue “enhanced” LORAN (eLoran) as a national PNT backup to the Global Positioning System (GPS) for the U.S. homeland. As a result, DOT and DHS are jointly preparing proposed transition plans to move operations, maintenance, construction, and funding for the Loran system from DHS /Coast Guard to another government agency so that eLoran may be implemented, upon which the Secretary of Homeland Security and the Secretary of Transportation can base a final decision on the future of the current Loran system, **DHS and DOT are in the process of completing these actions and are scheduled to make a joint announcement of a decision on Loran by the end of this year.**
Also Fits Nicely in Future PNT Evolved Architecture Baseline
eLoran Transition Plan in Process

Key Issues to be Addressed

1. Outline of the steps necessary to transition the current Loran-C system to an enhanced Loran (eLoran) system that will support both the current Loran-C user communities and a broader set of position, navigation, and time users that require higher levels of accuracy, availability, integrity, and continuity than currently provided by Loran-C;

2. Outline of the steps necessary to transition the United States Coast Guard’s current Loran system responsibility and authority to another U.S. Government agency; and

3. Establishment of the means to operate the system in the most effective and efficient manner.

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16 October 2007
**eLoran Transition Plan in Process**

**Key Objectives**
- Document system requirements and define an optimal concept of operations (CONOPS)
- Ensure quality and continuation of Loran PNT services and facilitate eLoran capabilities
- Reduce “total cost of ownership” by ensuring that the eLoran system will be operated in the most efficient and effective manner at a much reduced
- Reduce number/involvement of US Government personnel

**Key Milestones**
- Establish initial and final operational capability milestones of eLoran PNT services that will support multiple users communities

**Key Ancillary Products**
- eLoran Mission Need Statement
- eLoran System Requirements Requirements Document
- eLoran Signal Specification
Loran System Evolution Continues

We are going here

“Modernized”

Loran-C 2001

We were here

Loran 2007

We are here

eLoran 20??*

*TBD as part of Transition Plan
<table>
<thead>
<tr>
<th>Status Today</th>
<th>Loran-C</th>
<th>Modernized Loran</th>
<th>eLoran</th>
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<tbody>
<tr>
<td><strong>Aviation</strong></td>
<td></td>
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<tr>
<td>EnRoute (RNP 2.0 -&gt; 1.0)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Terminal (RNP 0.3)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>NPA (RNP 0.3)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td><strong>Maritime</strong></td>
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<tr>
<td>Ocean</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Coastal Confluence Zone</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>HEA</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<td><strong>Time/Freq</strong></td>
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<tr>
<td>Stratum 1 Frequency (1x10^-11)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Time of Day/Leap Second/UTC Reference</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Precise Time [&lt;50 ns UTC (USNO)]</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Area</td>
<td>Major Change</td>
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<tr>
<td>Radionavigation policy</td>
<td>Airport survey to generate ASF database for NPA/enroute</td>
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<td>Harbor entrance survey to generate ASF database for HEA</td>
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<td>Operational Doctrine</td>
<td>Time of transmission (TOT) control</td>
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<td></td>
<td>Off air to indicate out-of-tolerance conditions at station</td>
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<td></td>
<td>Continuous phase changes to correct timing errors at stations</td>
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<td>Long-term synchronization to UTC using at least one GNSS-independent means</td>
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<td>System Equipment</td>
<td>All stations use solid state transmitters (SSX)</td>
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<td>New uninterruptible power supplies and antenna coupler</td>
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<td>New timing and frequency equipment (TFE) to control timing</td>
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<td>New cesium clocks (three per station)</td>
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<td>Improved monitor network using existing sites</td>
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<td>Loran Data Channel (LDC) - ability to add digital data to the Loran signal</td>
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<td>Installation of transmitter control set (TCS) and remote automated integrated Loran (RAIL) equipment allows for the monitoring and control of all station equipment</td>
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<td>User Equipment</td>
<td>Ability to incorporate propagation delay tables for specific applications</td>
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<td>All-in-view capability (use all available stations regardless of chain)</td>
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<td>Improved cross rate interference mitigation</td>
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<td>Improved impulsive noise mitigation</td>
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<td></td>
<td>Ability to demodulate ninth pulse LDC communications</td>
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<td>Antennas (H field) to mitigate precipitation static (when necessary)</td>
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</table>
It’s about time -- really! The eLoran Clock

• Loran Stations (US and Canadian) and the Loran Support Unit each have 3 new cesium clocks
  – 90* very high stability clocks geographically dispersed across North America

• All 90 clocks can be steered to UTC (USNO) (independently from GPS) with great accuracy

• Establishing a robust Loran clock akin to, but totally independent from the GPS clock, is a valuable national asset

*(29 Loran Stations + LSU) x 3
Findings - Precision Timing

• “GPS serves as a precision timing source for 100,000,000 cell phone customers in North America and 250,000,000 worldwide.”
  
  B. Greene, VP, Lucent, brief to DOC GPS Forum, Jan. 2006

• “Under no circumstances should the Government place total reliance on GPS and completely abandon its plans to continue to deploy eLoran.”
  
  • Sprint Nextel Corp., comments in Federal Register, Feb. 2007

• “The proposal to develop an eLoran system would effectively address the need for a nationwide, distributed backup system. It is not clear that any widely reliable backup system exists now.”
  
  M. Lombardi, NIST, DHS briefing, July 27, 2006
NIST Report on Time Backups for GPS

• “We have reviewed all of the available broadcast signals that anchor the time and frequency infrastructure in the United States.”

• “We conclude that eLoran is the best available backup provider to GPS as a reference source for precise time synchronization and frequency control.”
North American Loran Time Coverage

90 cesium clocks geographically dispersed across North America
New eLoran Timing/Research/Monitor Receiver
New eLoran Timing/Research/Monitor Receiver
It’s also about “place”
Geo-encryption – Something New

Who can receive the encrypted file?

Conventional Cryptographic Algorithms

Who has the random key?

Geo-encryption and Signal Authentication

Who has the navigational receiver & can locate at the right location

\[
3400 \text{ m}^2 / 153,295,000 \text{ km}^2 = 2.2 \times 10^{-11}
\]
Data Collection Underway

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16 October 2007
“It’s not your grandparent’s (or your parent’s) Loran!”

Enhanced Loran (eLoran) Definition Document

Report Version: 1.0
Report Version Date: 12 January 2007

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16 October 2007
Loran from an International Perspective

- Enhanced Loran (eLoran) Definition Document published by the International Loran Association to provide a high-level definition of eLoran for policy makers, service providers, and users.
- Developed in November 2006 at the United States Coast Guard Navigation Center by an international team of authors.
- States that eLoran
  - is an internationally-standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications that takes full advantage of 21st century technology.
  - meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbor entrance and approach maneuvers, land-mobile vehicle navigation, and location-based services, and
  - is a precise source of time and frequency for applications such as telecommunications.
  - allows GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.
What’s Next? – My Crystal Ball

• 2008 – 2011
  – Decision on eLoran!!!
  – Completion of Modernization at St. Paul
  – Installation of commercial power at Shoal Cove
  – Initial Operational Capability (IOC) of eLoran precise time in CONUS
  – Proliferation of eLoran Time as primary reference system alternative
  – Commencement of RTCM work on eLoran standards for Maritime
  – Commencement of RTCA work on eLoran standards for Aviation
  – Testing/acceptance of prototype unmanned eLoran transmitting facility

• 2012 - 2015
  – IOC of Harbor Entrance and Approach at selected locations in CONUS
  – Certification of eLoran avionics/ IOC of Non-Precision Approach at selected locations in CONUS
  – Completion of eLoran modernization in Alaska
  – Use of second (10th Pulse) eLoran data channel for reduced WAAS message broadcasts (as a result of L5 availability)
  – Final Operational Capability (IOC) of eLoran precise time in CONUS/GPS-independent synchronization of eLoran clock
“Far and away the best prize that life offers is the chance to work hard at work worth doing.”

-- Theodore Roosevelt
A Heartfelt **Thank You to All!**

1. **The migration from a Loran-C radionavigation system to enhanced Loran (eLoran) has been and is key to the system’s continuation.**

2. **If it were not for the work of those in attendance here today and the work of many, many more dedicated people who could not be here, the Loran system in the United States, and perhaps the world, would have ceased to exist in the 21st Century.**

3. **We’re not there yet, there’s still much to do, but every team needs to celebrate its achievements – this team has much to celebrate -- and much to be thankful for!**
Summary

• The Future is Bright!

• Modernization efforts are continuing
  – St. Paul, Alaska Loran Station modernization ongoing
  – Airport and Harbor surveys to support NPA/HEA operations ongoing
  – GPS-Independent UTC Synchronization work ongoing
  – Navigation and Time receiver development ongoing

• eLoran Decision “in process”

• Awaiting announcement by SecDOT and SecDHS this year! (really!)
Questions
Timing accuracy model – Description & Comments

• **Non-differential (slide 2)**
  – Accuracy is rss sum of:
    • 30 ns for combination of receiver bias & transmitter accuracy
    • A noise term with noise at the 95% level, 10dB credit for clipping and 20 second averaging
    • A term based on map of seasonal variations in propagation
      – Because seasonal variations dominate in the rss sum, and western US has smaller seasonal variations, model shows better accuracy in west

• **Differential**
  – Differential Accuracy is rss sum of:
    • 30 ns for combination of receiver bias & base station error
    • Same noise term as above
    • A term proportional to distance from closest base station (currently 0.5 ns/nm)

• **Overall accuracy (in slide 3) is the minimum of the two accuracies above**
  – Slide 4 shows which is minimum, except for NE US, differential corrections do not help *timing* users, because *navigation* (HEA) users need to use much more distant stations, they still need differential corrections in the west

• **Current model suggest need for either station or monitor in Iowa/Nebraska**
  – Previous studies had suggested transmitter in this area would considerably enhance RNP availability.
Improvements Needed to Achieve eLoran Capability

• Aviation - NPA
  – Implementation of Loran Data Channel (LDC) via 9th-pulse communications to broadcast:
    • Station ID
    • Integrity Message
    • Early Skywave warning
  – Improved monitor system to detect skywave and out of tolerance condition
  – Time of Transmission (TOT) Control
  – ASF value(s) for each airport
  – Certified avionics (eLoran/multimode) to allow use of existing RNP 0.3 approach and landing procedures
Improvements Needed to Achieve eLoran Capability

- **Maritime - HEA**
  - Implementation of Loran Data Channel (LDC) via 9th-pulse communications to broadcast:
    - Station ID
    - Integrity Message
    - Differential Loran Information
  - Improved and expanded monitor system to provide real-time differential corrections to support 8m-20m accuracy requirement
  - Time of Transmission (TOT) Control
  - Harbor surveys to establish ASF grid
  - Maritime receivers (eLoran/multimode) to provide required accuracy
Improvements Needed to Achieve eLoran Capability

• **Time**
  – Implementation of Loran Data Channel (LDC) via 9\textsuperscript{th}-pulse communications to broadcast:
    • Differential Loran Information
    – Improved and expanded monitor system to support precise time (<50ns)
    – Time of Transmission (TOT) Control
    – *eLoran* Time receivers to provide required accuracy

• **Frequency**
  – *Nothing* \(\rightarrow\) We’re already Stratum 1! \((1 \times 10^{-11})\)
GPS/WAAS/eLoran Receivers for Aviation

Phase I

Phase II

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Example Aviation Tests: Rockwell/ Locus Integration of GPS-IMU-Loran

• AHC-3000A AHRS modified to add IMU outputs

GPS-Loran Antenna inside radome
GPS/WAAS/eLoran Receivers for Maritime
Tampa Bay Measurements
Megapulse/Reelektronika Receiver
April 2004