White Paper

GPS Backup
For Position, Navigation and Timing

Transition Strategy for Navigation and Surveillance

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FOREWORD

This white paper serves as a continuation of the Federal Aviation Administration's (FAA) *Navigation and Landing Transition Strategy*, originally issued in August 2002 that introduced the issues and strategies associated with reducing the cost of navigation (through decommissioning), the future dependency on satellite-based navigation, and options to provide backup for navigation. Since that time, the FAA has also decided to pursue acquisition and deployment of automated dependent surveillance – broadcast (ADS-B) as the primary means of surveillance. This dependent surveillance relies on satellite navigation to provide precision position reports.

The Joint Planning and Development Office (JPDO) responsible for defining the Next Generation Air Transportation System (NGATS) has also identified precision performance and four-dimensional (4-D) trajectory-based separation. This new way of dealing with aircraft separation introduces the use of time to what has previously been longitudinal, lateral and vertical separation.

What has also changed since 2002 is a thorough technical and infrastructure upgrade to Loran C, introducing new capabilities that can make Loran C a viable candidate as a backup for both navigation and surveillance. This new Loran is called Enhanced Loran, or eLoran.

This paper updates information from the 2002 Navigation and Landing Transition Strategy, presents strategies for backups, and discusses key policy decisions around precision navigation, timing, and surveillance.

To avoid confusion when addressing Loran, there are three distinctions that are made:

Loran-C is a method of navigation that uses a master station and a chain of stations tied to that master station to derive position.

Loran modernization is the physical upgrade of existing transmitters and associated equipment to improve performance and provide lower maintainability costs. A modernized Loran station still supports Loran-C.

Enhanced Loran adds to the performance of the stations and introduces a new avionics design called "All-in-View" that treats every Loran station transmitter as if it were a GPS satellite bolted to the ground. Enhanced Loran is the basis for the breakthrough in avionics performance necessary to support a position and navigation backup to GPS.

EXECUTIVE SUMMARY

On September 11, 2001 we saw the need for reliable safety, security and social support networks and services. Almost exactly four years later, the even more widespread devastation by hurricanes on the U.S. Gulf Coast pointed out again the need for robust and resilient backbone infrastructures to protect the public health and wellbeing. These events show the effects of cascading unavailability of goods and services that are necessary or customary – at least, expected or assumed -- in the American model of governance and economics.

Hurricanes Katrina and Rita in particular offer insight into what happens when communications, transportation and public safety are all removed. Our social fabric is revealed as a rather fragile set of agreed-upon behaviors, supported by what we now call critical infrastructure. *Remove that basic foundation, and the ugly products of opportunism and desperation set in.* America's social and economic wellbeing is dependent upon certain critical infrastructures, power, water, communications, transportation, financial, and our ability to continue to provide vital Government services in the presence of disasters, whether man-made or natural. One of those vital services is PNT or Positioning, Navigation and Timing.

The FAA's Navigation and Landing Transition Strategy, published in August 2002, defined the satellite navigation transition strategy that considered the vulnerability of the Global Positioning System (GPS) and described proposed requirements for a backup navigation and landing capability for the National Airspace System (NAS).

The report also provided input to the Department of Transportation's action plan to maintain the adequacy of backup systems for critical transportation applications in which GPS is being used. The strategic transition ensures that adequate ground-based navigation aids (navaids) are maintained and that the appropriate mix of systems is described that addresses GPS vulnerabilities. This paper picks up where the previous strategy ended and updates information, especially on changes to Loran, and examines the other possible backups to GPS, mainly inertial navigation systems augmented by additional distance measuring equipment (DME) and a minimum operating network of existing very-high frequency omni-directional range (VOR). This paper is organized by first providing high-level requirements for continuing operations in the event of GPS interference. It then discusses navigation performance in various flight domains, updates the status of Loran, compares options for backup in terms of cost, discusses strategies for ADS-B, and recommends a transition path to implementing a backup strategy. Throughout the paper, the history and evolution of public policy is discussed. Public policy is the remaining link in deciding a backup strategy.

Operational Requirements

The operational requirements for a backup and redundant capability are based on disruption of navigation, most likely by interference. The impacts are not local. Typically, 200-300 miles radius from the interfering source characterizes the affected area depending on aircraft altitude. In a deliberate event, multiple interference locations can be anticipated. Another scenario of concern is the mobile and intermittent intentional interference, to avoid detection and apprehension. In this case, interference is a menacing, long-term disruptive event. While safety can be maintained, the loss of GPS in the absence of a backup will cause significant economic disruption in transportation of people and goods.

The greatest deterrent to selecting GPS as a target is if the consequences of such and act are go unnoticed or are so minor that the value as a target is diminished. This is the greatest value for a backup to GPS. So far, GPS has not been a deliberate target, principally because of legacy navaid redundancy. The first obligation for a backup is safety, followed by continuing to maintain close to the same capacity, denying GPS as a high-value target and preserving our economy. Therefore, the operational requirements are fairly straightforward:

1. Aircraft flying in the NAS shall be capable of safe flight to landing at their airport of destination or a suitable alternate.
    a. Aircraft in instrument meteorological conditions (IMC) must have sufficient backup navigation to follow a route, transition to an approach, and land at the airport using flight instruments.
    b. Aircraft in visual meteorological conditions (VMC) shall continue to maintain visual references until landing at the airport of destination or a suitable alternate that is visual.
2. Instrument landings shall be guided by either 1) an instrument landing system for the runway, or 2) the aircraft shall be capable of performing a required navigation performance (RNP 0.3) non-precision approach in the absence of an ILS.
3. Air carrier, cargo carriers, and high-end general aviation shall continue to be able to depart from an airport suffering an interference event and continue to destination, whether or not that destination airport is also experiencing interference.
4. Other general aviation aircraft may elect to not carry a backup capability, but must limit flight to visual flight rules in the presence of interference.
5. Air traffic controllers shall not be required to provide radar vectors to all aircraft in the affected area of interference, other than for normal separation activities. Surveillance shall not serve as an acceptable backup during intentional interference for reasons of workload and the transition to satellite-based surveillance.

FAA's Current Strategy

The FAA would expand the existing network of distance measuring equipment (DME) to provide a redundant RNAV capability. A reduced set of very-high frequency omni-directional range (VOR) and non-directional beacon systems (NDB) (Alaska only for NDB) would be retained, described as the minimum operating network, to support a backup capability suitable for recovery of aircraft not equipped with a redundant RNAV capability. Many Category I instrument landing systems (ILS) would be retained to fulfill precision approach capabilities as a backup to ensure safe recovery of aircraft and continued operation of air commerce in the event of GPS interference. All ILSs used to support Category II/III operations would remain in service. These actions effectively reduce the threat to air transportation from the intentional disruption of satellite navigation. The continued development and deployment of diverse L1C, L2 and L5 frequencies on the GPS satellites adequately addresses unintentional interference. An intentional act would target these multiple frequencies and because the GPS signal is so low in power, could easily be overpowered with a jamming signal, even after power increases with the GPS III satellites.

The exact mix of ground-based navigation aids needs to be defined by specific locations and time for discontinuing services so that the users can assess the impact to their operation and plan their own investments in satellite navigation and adequate backup.

Loran Status Update

Thorough evaluations have been completed on the applicability of Loran for use as a redundant backup to GPS with changes beyond modernization that are tied to approach procedure development. Loran is an independent source of position, navigation and timing that is not subject to the interference vulnerabilities of GPS. These evaluations clearly show that an enhanced Loran is available and has the potential to meet non-precision approach requirements when updates are completed; being capable of delivering required navigation performance of 0.3 nautical miles (RNP-0.3), as does GPS. There must be a long-term commitment made—with its associated investments—to the continuation of Loran, so that a market can immerge incorporating Loran into the GPS/WAAS avionics. This paper updates information on Loran and also provides a strategy for development of an integrated backup capability. DME and ILS do not support all of the domains in meeting the operational requirements for an interference or GPS outage event, but DME enables INS updates for en route and terminal operations and ILS supports precision landing for low-visibility operations. eLoran maps directly to all of the operational requirements. The only exception is for a precision approach (glide path available). If the aircraft has a flight management system, the eLoran position could be matched to barometric information to produce vertical guidance. In most weather conditions lack of vertical guidance is acceptable because ILS is being retained and eLoran can produce an arrival path to the ILS intercept. Commercially available avionics can be available by 2009, providing standards development begins in 2006.

Backup Equipage Strategy

There are several assumptions that bring the timing of this strategy and its components together. It is a nexus of events that creates the opportunity to resolve the backup strategy, accelerate equipage, and begin decommissioning of surplus navigation aids.

- Significant new air carrier aircraft deliveries are expected starting in 2008 with the B787, B747-8, A380, and A350, as well as continuing strong orders for next generation B737 products. In the presence of clear policy, the backup can be added to the navigation suite.

- Some general aviation avionics manufacturers are currently offering an upgrade from GPS to GPS WAAS starting this year. A backup decision can prepare the general aviation avionics manufacturers to create upgradeable interfaces to these GPS/WAAS avionics packages and begin work on GPS/WAAS/eLoran integration.

- Galileo is to become operational in 2012. This adds 30 more satellites to the constellation for navigation. It is important to note that the European Union is developing a radionavigation plan that considers eLoran as a viable source for backup.

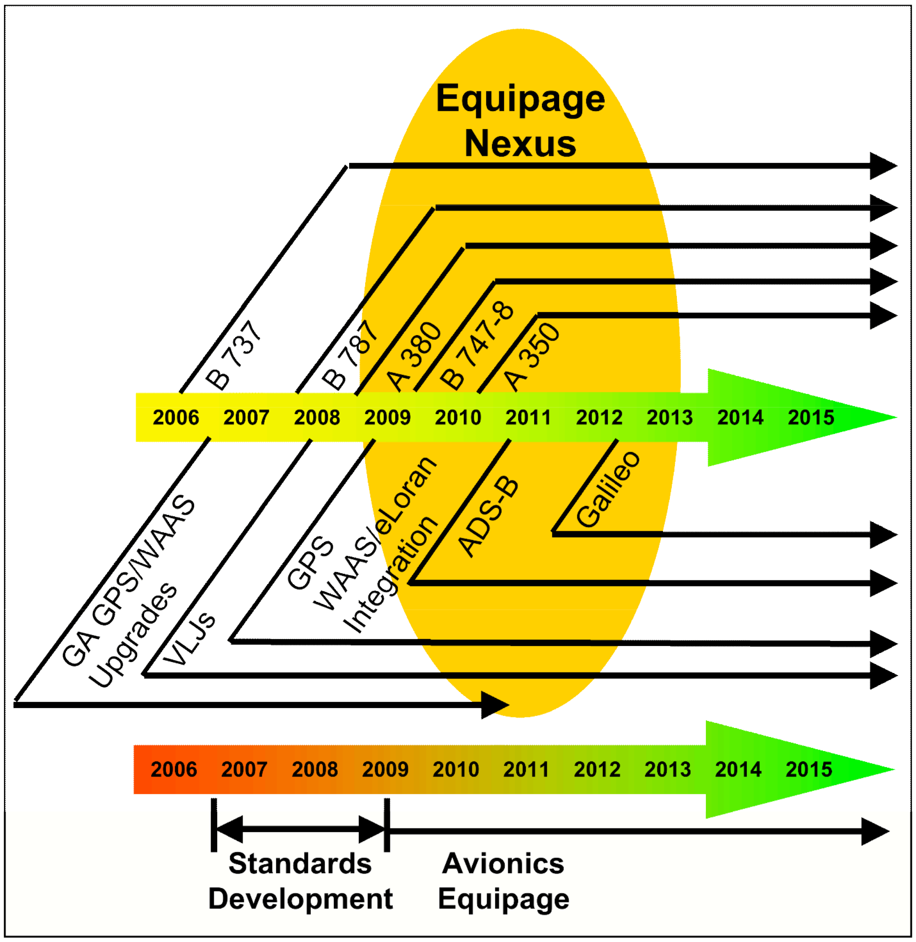
- ADS-B will be introduced in 2009-2010 and the backup for surveillance need not be resolved early for en route, due to the existence of secondary surveillance, but in the Gulf of Mexico airspace, if separation is to be reduced to the equivalent of en route radar separation then an on-board ability to derive and report position is required.

- Sufficient RNP approaches are in place at the 100 top airports to shift toward an all RNP airspace, creating the opportunity to reduce selected VORs early and restructure the airspace to favor equipped aircraft.

This nexus around 2009 to 2010 provides the opportunity to make the GPS/WAAS/eLoran box cost beneficial with a clear path to accelerated RNP operations. Even general aviation can share in this integration, at a modest cost above the basic GPS/WAAS through the use of eLoran chip sets in the avionics. This same integration should provide the interfaces to use Galileo. Once standards are approved, the FAA can define a schedule for an all RNAV National Airspace System, breaking dependence on Jet Routes and Victor Airways for aircraft separation. This change in airspace coincides with the deployment of the replacement automation for the en route environment. As equipage continues, benefits increase through efficiencies gained in use of the airspace.

Figure E-1 summarizes the nexus and value of integrating the backup into the upgrades for GPS with WAAS and the interfaces for Galileo. Adding eLoran provides an area navigation backup for the area navigation capabilities of GPS. Note that the timing for development of standards must start this year to begin the transition and accelerate decommissioning of ground-based navaids. The reason eLoran will only take two years for standards are that there are prototype-integrated avionics available to help with the standards process and the ongoing Loran enhancement and modernization efforts are already addressing many of the challenges leading to avionics certification.

Figure E-1 Avionics Integration Business Case – Nexus of Opportunity



The Value of a Backup

GPS and WAAS are national and international assets that provide services well beyond aviation and marine harbor entry. The DOD provides the GPS and the DOT provides the augmentations that are being widely accepted for a multitude of new services. GPS has stimulated the economy and businesses have grown up around the signal in space provided by these satellites. Every day, millions of our citizens directly touch GPS. Consider cell phones, E911, car navigation systems, flying in an airplane, recreational boating, banking and finance, or getting on a network to exchange information. Millions of other citizens are the beneficiaries of the efficiencies gained by cargo carriers and information service providers.

From a safety perspective, in the event of GPS interference, aircraft can be recovered and other flights prevented from flying. Ships entering harbors can drop anchor and wait off shore at great economic cost. E911 will not be as efficient, but the possibility of loss of life is small. But the economic consequence of halting segments of transportation due to the lack of PNT and impacting our nation's communications, power grid and other critical functions dependent on precise timing is measured in minutes, hours and days. Finding the source of intentional interference in minutes, hours or even days is unlikely, as evidenced from previous unintentional jamming events. Trying to locate deliberate disruptive events will be even more difficult than past experience with unintentional interference. Interferers may be mobile, intermittent, or geographically dispersed.

From a security standpoint, the best defense against an attack on GPS is to lower the target value by providing a sufficiently robust national backup that allows PNT to continue in a way that there is a significantly reduced safety risk and direct impact on our economy. Several hundred USCG personnel and $27 million a year are providing a capability that protects the value of PNT with eLoran. The issue of supporting a backup cannot be the funding. There are nearly 300,000,000 people in the United States – that is an insurance policy against PNT disruption that works out to less than 9¢ per year per citizen. In the context of the overall budget for homeland security, the federal responsibility to provide a backup is cost beneficial to both the citizens and those in Government who provide navigation services.

The debate about continuing Loran cannot be around the willingness to use Loran. With over 10 years of uncertainty on continuing Government support of the signal, most former users have found other more expensive means of providing backup, especially the precise timing segments of our economy. With the right Government leadership and commitments, many of these segments will return to Loran, transportation users will benefit from the advances that make eLoran possible, and a true backup to GPS will become as ubiquitous as GPS itself.

If it is not the money and not the current user base, then the issue must be the staffing, the number of Coast Guard positions that are tied up in operating the 28 Loran stations. These women and men could be doing other higher priority work in our nation's homeland defense. The solution here is to either 1) divest the responsibility for Loran from the Coast Guard, or 2) outsource the operations and at the same time reduce the overall cost of providing the backup but retain responsibility within DHS.
For navigation, DHS would provide, from their budget, the national backup used by aviation and others, providing an integrated solution to protect PNT as a national asset.

From an economic standpoint, disruption to transportation, even if on a regionalized basis, will be very costly. Repeated intentional interference events without existence of a backup would stop flight operations, create a loss of confidence in aviation and navigation, significantly increase controller workload, and leave containerships anchored off our ports. Distribution of goods would be impacted. Depending on the duration of the interference, communications and the national power grid could be impacted as their timing backups degrade.

Figure E-1 compares the technologies proposed for backup against the political, operational, economic and technical challenges that each alternative faces. While there is significant experience and understanding with ILSs, VORs and DME, the enhancements to eLoran are new developments supported by research, flight trials and analyses as directed by the Congress.

Loran has changed from a "might do" in 2002 to a "can do" in 2006. It is the lowest cost national technology that provides full PNT backup for GPS, well beyond just transportation. With similar stations in Europe and Asia, the majority of global air transportation is within the coverage area of Loran – it is not just a U.S. solution.

Figure E-2 Challenges with Backup Candidates

Technology	Political	Operational	Economic	Technical
GPS RNAV WAAS (for comparison) E	Well Supported Demand for Non-aviation Services Strong	Full RNAV RNP 0.11 for Approaches 200 feet and 1/2 mile Vis	Stimulating Economic Growth In Products And Services	Require ILS for Below 200 feet And 1/2 mile Vis
INS DME/DME RNAV E	On Board Autonomy For En Route And Terminal	Approach to ILS or VOR Landing Only	Recapitalization And Addition of More DME Near Airports	No INS Only Approaches Inertial Precession at 2 nm/hour
VOR Minimum Operating Network	Resistance to Removal of Selected VORs Harder than Full Removal	Not an RNAV Backup Requires Training and Procedures	Recapitalization Of Retained VORs	Coverage and Airports Yet To Be Identified
Retained ILSs	Congressional Resistance to Removal of Any ILSs	Backup for Landing Only	Retained for Capacity in Low-Vis Operations	Closely-Spaced Parallel Ops Impacted by Localizer Overlaps
eLoran E	Strong Congressional Support for Funding and Decision	Full RNAV RNP 0.3 for En Route and Approaches	CONUS Capitalized Lowest Operations Cost	RTCA Avionics Standards Required

E **Equipage required by significant segment of fleet**

Equipage is a key issue that must be addressed and is totally dependent on public Policy. Public policy on the Government-provided PNT backup must be completed by 2007 so as to take advantage of the nexus of events around improvements to GPS, implementation of WAAS, introduction of Galileo and ADS-B, and changes in en route automation. This window of opportunity will lead to equipage with a backup that is transparent to the users, and with eLoran, it would be an RNAV backup for an RNAV GPS navigation system plus the additional benefit of a full PNT complement for the rest of America.

Dr. Brad Parkinson is considered the father of GPS, certainly one of the most knowledgeable scientists regarding GPS, its performance and future improvements. In a recent interview for the *European Journal of Navigation*, he responded to a direct question on interference:

> *"MEMS[micro-electrical-mechanical systems] inertials and beam-steering antennas are important in coping with interference. There are two things that are happening. The costs of MEMS inertial sensors are plummeting. They are being used to cope with interference. But the other thing is the move toward beam-steering antennas. Some people started out with multiple null-steering antennas. When you have multiple jammers, it is not solving the problem. Beam steering is a more effective technique. We now have the ability to go from analogue to digital at very high frequencies; as a mater of fact, they are actually L-band digital chips. And having enough bits of the sample, you can actually phase add and subtract to get the various beams to the satellites. I can visualize even cars having the antennas distributed underneath the paint on the whole roof and having a very jamming resistant car. Here you have Brad the great visionary! I think that is an example. But independent of that one, I am a supporter of having a backup radio navigation system, and the only backup system I can see is Loran. And I can see further that GPS helps Loran or Loran helps GPS. I think that's a great idea. It is mutually aiding, depending on the type of integration. One of the fundamental reasons that I have come back to this is that it is a deterrent. Because a terrorist would probably not decide to jam GPS when he has the recognition that we have Loran as a backup, which is a very difficult thing to jam. When we extensively publicize that there are four or five civil satellite signals and, secondly, we have Loran as a backup, it will take the fun away."*

From Common L1C Enormous Benefit to Everyone, Interview,
European Journal of Navigation, Volume 4, Number 4, September 2006

Dr. Parkinson, the European Community, and PNT professionals recognize the need for a backup to satellite-based positioning, navigation and timing. It is time to make the public policy decisions to protect GPS, well before GPS becomes such a significant element of our economy that the value as a target escalates to the point of a threat to our nation.

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Introduction

FAA’s Navigation and Landing Transition Strategy

The FAA’s Navigation and Landing Transition Strategy, published in August 2002, defined the satellite navigation transition strategy that considered the vulnerability of the Global Positioning System (GPS) and described proposed requirements for a backup navigation and landing capability for the National Airspace System (NAS).

The report also provided input to the Department of Transportation’s action plan to maintain the adequacy of backup systems for critical transportation applications in which GPS is being used. The strategic transition ensures that adequate ground-based navigation aids (navaids) are maintained and that the appropriate mix of systems is described that addresses GPS vulnerabilities. The transition time is through the full deployment of the next generation of GPS (GPS III), which brings improvements that address elements of the current vulnerabilities.

The navigation and landing strategy focused on sustaining safety during GPS disruption for operations in instrument conditions and recovery of aircraft operating within an interference area. Sufficient ground-based navaids are to be retained to meet this NAS safety responsibility. Navigation equipment used by the Department of Defense (DOD) is retained for homeland defense (tactical air navigation or TACAN). Sufficient navigation infrastructure must also be retained for capacity and efficiency to continue commercial flight operations. Continuing operations by air transportation in the presence of interference is the best deterrent to the deliberate disruption of satellite navigation.

The transition is dependent upon the increased service provided over existing ground-based Navaids in instrument meteorological conditions with operations continuing in the presence of interference. The FAA cannot financially support the development, deployment and operation of satellite navigation and also re-capitalize and operate the entire existing ground-based infrastructure, making satellite navigation just another layer of navigation. The FAA recommended the sustainment of a reduced number of existing navaids to provide both a redundant and backup capability for en route navigation, non-precision approach, and precision approach.

Redundancy was defined as being able to navigate apart from the airway structure using area navigation (RNAV). A backup capability is dependent on flying directly between retained ground-based navaids.

Ground-based Navaids Retained

The FAA would sustain the existing network of distance measuring equipment (DME) to provide a redundant RNAV capability. A reduced set of very-high frequency omni-directional range (VOR) and non-directional beacon systems (NDB) would be retained, described as the minimum operating network, to support a backup capability suitable for recovery of aircraft not equipped with a redundant RNAV capability. Many Category I instrument landing systems (ILS) would be retained to fulfill precision approach capabilities as a backup to ensure safe recovery of aircraft and continued operation of air commerce in the event of GPS interference. All ILSs used to support Category II/III operations would remain in service. These actions effectively reduce the threat to air transportation from the intentional disruption of satellite navigation. The continued development and deployment of diverse L1C, L2 and L5 frequencies on the GPS satellites adequately addresses unintentional interference.

Intentional interference would target these multiple frequencies and because, notwithstanding the planned signal strength increases, the GPS signal is low in power and can be overpowered with a jamming signal.

The exact mix of ground-based navigation aids needs to be defined by specific locations and time for discontinuing services so that the users can assess the impact to their operation and plan their own investments in satellite navigation and backup.

In 2002, the European Union decided to pursue Galileo, an independent satellite navigation system. While the Galileo signals could further improve how robust satellite navigation is to unintentional interference, they would not mitigate intentional interference, as their power levels and operating frequencies are very similar to GPS. While 30 more satellites will improve availability for navigation, intentional interference still remains an obstacle to overcome.

After identifying the need for a backup against intentional interference to satellite navigation, the policies regarding redundancy and backup strategies have yet to be issued. Clear public policy is essential to stimulating investments in airborne equipment and making a practical choice to either carry a backup or accept the risk of an outage.

PNT

Navigation has evolved to Positioning, Navigation and Precise Timing (PNT) services provided by the Government. PNT is recognized as part of our national critical infrastructure. We use PNT daily to communicate, to move goods and services, to protect life and property, for military effectiveness and services well beyond aviation and transportation.

PNT services have become a national/global requirement. Having such capabilities is taking on the role of a public utility, as common as the telephone or electricity. Services range from precision agriculture, location services, E911 emergency services, and a host of communications activities supported by precision timing. Use of PNT has led to applications increasing daily – dependence also increases daily – the consequences of disruption increase daily.

Protection of the PNT service from natural or man-made interference or failure provides increased assurance that the wide variety of critical infrastructures, which depend directly on PNT, or on transportation, communications, power grid, or other services directly enabled by PNT, will be available in good times and bad. Current U.S. policy specifies that such protection will be provided through backup systems or other means without naming how. Transportation users need to know what signals will be provided to back up GPS so they can plan their investments.

GPS Vulnerability

The landmark "Volpe Center Report"[1] on the vulnerabilities of the GPS system to intentional or unintentional interference was released on September 10, 2001, just one day before the security of our Critical Infrastructure and even our way of life was forced to center stage. Events since then have validated the Volpe Report's conclusions. A 2003 solar storm affected GPS-based services to aviation.

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[1] John A. Volpe Transportation Systems Center, "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System," August 2001

Recent news reports[2] have quoted an FBI affidavit charging two men with "…plotting to disable the global positioning system in an effort to disrupt military and commercial communications and traffic." The GPS has become a target[3].

Through the provision of alternative sources for PNT services, we increase the availability of *enough of the principal system's functions* that users can continue to operate safely if the principal system like GPS is lost. When both systems are operating, they can be crosschecked, raising confidence in the availability of the safety-net systems for service when and if the principal system fails.

When we provide a dissimilar alternative – a safety net – we reduce the "high-value-target" status of a principal system. Its loss or compromise does not cripple the functions that depend upon it in normal times. Far from an "insurance policy" in the event of intentional interference, provision of a redundant capability diminishes the value of disruption.

Organization of this Paper

Efforts have been completed to examine the applicability of Loran-C for use in the NAS as a redundant backup to GPS. Loran-C is an independent source of position, navigation and timing that is not subject to the interference vulnerabilities of GPS. Loran is available now and meets non-precision approach requirements, being capable of delivering required navigation performance of 0.3 nautical miles (RNP-0.3), the same as GPS. There must be a long-term commitment made—with its associated investments—to the continuation of Loran, and a market must be created for incorporating Loran into the GPS/WAAS avionics. This paper updates information on Loran and also provides a strategy for development of an integrated backup capability.

This paper is organized by first providing high-level requirements for continuing operations in the event of GPS interference, discusses navigation performance in various flight domains, updates the status of Loran, compares options for backup in terms of cost, discusses strategies for ADS-B, and recommends a transition path to implementing a backup strategy.

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[2] "FBI: Georgia men talked of U.S. terror plan," Henry Schuster, CNN, Friday, April 21, 2006

[3] Dow-Jones Newswires June 22, 2006: "Lt. Gen. Robert Kehler, deputy commander of U.S. Strategic Command, said recent attacks on U.S. satellite guidance systems mark the emergence of a new threat. Iraqi insurgents' attempts at blocking global positioning system, or GPS, signals have been crude so far, but have spurred new emphasis on protective measures."

Operational Requirements

The operational requirements for a backup and redundant capability are based on interference and human failures. There are likely to be deliberate acts to interfere with navigation (and ultimately surveillance). Unintentional narrow-band interference can be countered by the second civil frequency of GPS and by locating and turning off the interference source. Most unintentional interference to date has been caused by the military and its contractors. Procedural changes implemented by the DOD can reduce the incidence of unintentional interference.

These limited unintentional interfering events help to characterize the potential impact to aviation. The impacts are not local. Typically, 200-300 miles radius from the interfering source characterizes the affected area. In a deliberate event, multiple interference locations can be anticipated. Another scenario of concern is the mobile and intermittent interference, to avoid detection and apprehension. In this case, interference is a menacing, long-term disruptive event.

The greatest deterrent to GPS as a target is if the consequences of the act are non-existent or so minor that the value as a target is diminished. Continued operations are necessary. Therefore, the operational requirements are fairly straightforward:

1. Aircraft flying in the NAS shall be capable of safe flight to landing at their airport of destination or a suitable alternate.
    a. Aircraft in instrument meteorological conditions (IMC) must have sufficient backup navigation to follow a route, transition to an approach, and land at the airport using flight instruments.
    b. Aircraft in visual meteorological conditions (VMC) shall continue to maintain visual references until landing at the airport of destination or a suitable alternate that is visual.
2. Instrument landings shall be guided by either 1) an instrument landing system for the runway, or 2) the aircraft shall be capable of performing an RNP 0.3 non-precision approach in the absence of an ILS.
3. Air carrier, cargo carriers, and high-end general aviation shall continue to be able to depart from an airport suffering an interference event and continue to destination, whether or not that destination airport is also experiencing interference.
4. Other general aviation aircraft may elect to not carry a backup capability, but must limit flight to visual flight rules in the presence of interference.
5. Air traffic controllers shall not be required to provide radar vectors to all aircraft in the affected area of interference, other than for normal separation activities. Surveillance shall not serve as an acceptable backup during intentional interference.

<u>Operational Requirements</u>

- **Recover aircraft safely**
- **Provide instrument landings**
- **Continue to depart in the presence of interference and land at destination**
- **Air traffic controllers shall not use surveillance and vectoring to recover from an interference event**
- **General aviation may opt to not carry a backup, but would be restricted to visual conditions and denied access to certain airspace during an interference event.**

Backup Choices

The backup choices are made up of the existing mix of ground-based navigation aids that have a long history of performance. The use of non-directional beacons began in the late 1920's. Instrument landing systems were first installed in 1940 at the then Indianapolis Municipal Airport. The VHF Omni-directional Range system that makes up the Victor Airways and Jet Routes had its origins in 1944 with advancements in radios during World War II and was deployed in the early 1950's. The first navigable airway came into being in 1951. While VOR could provide azimuth, it did not provide distance from the station. In 1945, the Civil Aviation Authority began experiments with distance measuring equipment (DME) that became operational in 1951.

<u>Backup Choices</u>

INS with DME/DME scanning update of position for RNAV capabilities

Minimum operating network of VORs for VOR-to-VOR direct

ILS retained for precision landing

ELoran for full RNAV capabilities

TACAN retained for military operations

Loran positioning and navigation has an even longer history. The requirements that gave birth to Loran as a pulsed hyperbolic navigational system came out of the Army Signal Corps Technical Committee in 1940, as "Precision Navigational Equipment for Guiding Airplanes." This was taken seriously, as demonstrated by the dedication of an entire volume to Loran in the legendary MIT Radiation Laboratory Series[4], describing the design and implementation of the system.

The centerpiece for the future of navigation, GPS, also had early beginnings. The NAVSTAR System, has a longer history than we typically hear: "Timation" in 1964 (U.S. Navy), "Transit" in 1967 (U.S. Navy), "621B" in 1973 (U.S. Air Force), and finally the first developmental GPS satellites in 1974 and 1977.[5] The technology is over 30 years old. The GPS is now being modernized to "GPS-III" with additional services and performance-assurance features – leading to further-expanded dependence for civil aviation and the general public. As early as the late 1980's, GPS was being combined with broadcasting of positions to form automated dependent surveillance.

Inertial guidance systems, like the inertial navigation system (INS) provides position, velocities and attitude of the aircraft by measuring accelerations and rotations. An INS uses gyroscopes and accelerometers to solve a large set of differential equations to create estimates of velocities and positions starting from a known position of latitude and longitude. The limitation is that all INS avionics suffer from integration drift, the loss of precision over time. Typical drift is on the order of 2 nautical miles per hour, with the highest quality inertial systems meeting 0.6 nautical miles per hour. The advantage to INS is that it is self-contained within the aircraft and immune from interference. The disadvantage is its precession or loss of precision over time. Integrating GPS or using VOR/DME or

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[4] Pierce, J.A., et. al., Editors, *Loran: Long Range Navigation,* MIT Radiation Laboratory Series, Vol. 4, Lexington, MA, (Boston Technical Publishers, 1964).

[5] Pace, Scott, et. al.; *The Global Positioning System: Assessing National Policies,* Rand Corp., Santa Monica, CA., 1995, Appendix B.

scanning DME/DME can update the INS to compensate for integration drift. This drift is a key element in identifying the backup for air carrier aircraft equipped with inertial systems.

The maturity of the technology has created a significant base for aircraft equipage with ILS and VOR/DME. Approximately a third of the current air carrier fleet has INS with scanning DME/DME capabilities. Aircraft owners and operators are just now eliminating NDB and adding GPS and there is a significant avionics investment ahead to add wide-area augmentation (WAAS). The Aircraft Owners and Pilot's Association estimated in 2005 that 63 percent of their members use GPS, either as a hand-held device or panel-mounted avionics. The transition has started, but to date, few air carriers have invested in GPS/WAAS.

How Choices Map to Operational Requirements
For navigation, the need for a GPS backup is accepted; the question now is what is the best mix of legacy navigation aids to meet the operational requirements? Some segments of the aviation community, specifically general aviation that does little instrument flying, will not need a backup for navigation but may be restricted from airspace in the event of interference. For reasons of efficiency and capacity, continuation or our nation's economy, and security, commercial aviation needs to carry a GPS backup. Table 1 is a matrix of operational requirements against the technology choices.

Aircraft Safe Recovery - IMC			
NAVAID	**En Route**	**Terminal**	**Approach &Landing**
NDB	Value in Alaska with long-range NDB	No value with ongoing decommissioning	No value with ongoing decommissioning
VOR	VOR-to-VOR direct	Proceed direct hold at VOR	Execute non-precision approach (not RNP 0.3)
TACAN	Retained full recovery capability	Penetration approaches and arrival paths	Non-precision approach (not RNP 0.3)
Loran	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach
DME	No value without INS	No value without INS	No value without INS
ILS	Not applicable	No terminal area maneuvering guidance	Precision approach capability assuming RNAV or radar vectors to intercept the localizer
INS (no update)	Sufficient coast-to-coast (2nm/hour precession)	RNAV to ILS localizer intercept	Insufficient for RNAV approach without position update
INS (VOR/DME or DME/DME update)	Capable of RNP 2.0	RNAV to ILS RNAV approach	RNP 0.3 if updated during approach with multiple stations within 25 nautical miles of aircraft position and proper geometry
GPS for comparison	RNAV/RNP 1.0	RNAV/RNP 1.0	RNP 0.3 approach

Aircraft Safe Recovery - VMC			
NAVAID	**En Route**	**Terminal**	**Approach &Landing**
NDB	Value in Alaska with long-range NDB	No Value	No Value
VOR	Navigate VOR-to-VOR	Orient visually to airport if VOR on airport	Not needed for visual
TACAN	Retained full recovery capability	Penetration approaches and arrival paths	Non-precision approach (not RNP 0.3)
Loran	RNAV available like GPS	RNAV available like GPS	RNAV available like GPS
DME	No Value	No Value	No Value
ILS	Not applicable	Not Applicable	Not needed for visual
INS (no update)	Full RNAV capability	RNAV supports visual acquisition of airport and runway	Not needed for visual
INS (VOR/DME or DME/DME update	Full RNAV capability	RNAV supports visual acquisition of airport and runway	Not needed for visual
GPS comparison	RNAV/RNP	RNAV/RNP	RNAV/RNP

Instrument Landings			
NAVAID	**Precision**	**Non-Precision**	**RNP – 0.3**
NDB	No	Yes	No
VOR	No	Yes	No
TACAN	No	Yes	No
Loran	No	Yes	Yes
DME	No	No	No
ILS	Yes	Yes	Yes
INS (no update)	No	Yes	No
INS (VOR/DME or DME/DME update	No	Yes	Yes (update with DMEs located within 25 nautical miles and acceptable geometry)
GPS/WAAS	Yes	Yes	Yes

Continuing Operations - IMC				
NAVAID	**Departure**	**En Route**	**Approach**	**Landing**
NDB	No	No	Yes	Yes
VOR	Yes (SID)	Yes	Yes (STAR)	Yes
TACAN	Yes (SID)	Yes	Yes (STAR)	Yes
Loran	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)
DME	No	No	No	No
ILS	No	No	No	Yes
INS (no update)	Yes	Yes	Yes	No
INS (VOR/DME or DME/DME update	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)	Yes (RNAV)
GPS	Yes	Yes	Yes	Yes

Dependency on Radar Vectors			
NAVAID	**En Route**	**Terminal**	**Approach &Landing**
NDB	No vectors required	No vectors required	No vectors required
VOR	No vectors required	No vectors required	Vectors to ILS
TACAN	Jet Routes or Direct No vectors required	Non-precision No vectors required	Ceiling 500 ft and 3/4 mile visibility
Loran	RNAV no vectors required	RNAV no vectors required	RNAV/RNP 0.3 No vectors required
DME	Vectors required	Vectors required	Vectors required
ILS	Vectors to localizer intercept	Vectors to localizer intercept	Vectors for missed approach
INS (no update)	2 nm per hour acceptable for 2 hours	Approach and landing vectors required	Approach and landing vectors to suitable other navaid for approach
INS (VOR/DME or DME/DME update	No vectors required	No vectors required	No vectors required if within 20 minutes of outage, vectors for missed approach to a suitable navaid for next approach
GPS (no interference)	RNAV no vectors required	RNAV no vectors required	RNAV/RNP 0.3 No vectors required

As can be seen from the matrices above, DME and ILS do not support all of the domains in meeting the operational requirements for an interference or GPS outage event, but DME enables INS updates and ILS supports precision landing for low-visibility operations. eLoran maps directly to all of the operational requirements. The only exception is for a precision approach (glide path available). In most weather conditions this is acceptable because ILS is being retained and eLoran can produce an arrival path to the ILS localizer intercept.

Performance-based Navigation and NGATS

Under the FAA's "performance-based" navigation, airlines will be expected to use satellite guidance instead of ground-based navaids, promoting direct flights and saving the airlines fuel and time. The FAA's Performance-Based Operations Aviation Rulemaking Committee (PARC) released the second version of the "Roadmap for Performance-Based Navigation."[6] The newly updated information includes how the FAA plans to proceed and lays out the dates for mandates on the types of equipment that will be needed by not only the airlines, but also business aircraft and other general aviation operators. In the short term, the Government will take advantage of avionics and satellite technology already deployed, including RNAV procedures and instrument departures and arrivals in place at some major U.S. airports. In addition to RNAV, which could eventually be available throughout the continental U.S., required navigation performance (RNP) procedures will also play a major role. The first public-use RNP procedure was recently implemented at Reagan Washington National in Washington, D.C.

NGATS Concept of operations specifies performance-based services, network-enabled operations, and 4-D trajectory-based separation will require precision positioning, navigation and integration of time to keep the aircraft as a node on a network.

NGATS targets three times the traffic by 2025. To read more, go to www.jpdo.aero.

Procedure development is proceeding much faster than planned. Initial FAA plans called for 30 RNAV arrival and departure procedures for FY 2006, but that number may be as high as 60 to 65. The plan calls for five public RNP procedures, but that number could be as high as 30. This is significant because RNP approaches are granted today under special provisions requiring aircraft and aircrew qualifications and additional training.

By the 2011-2015 timeframe, RNAV approaches and departures are expected to be operational at the busiest 100 airports and RNP procedures at airports where the added precision produces benefit. The FAA would be publishing approximately 300 RNAV and 50 RNP approaches per year in that timeframe, and RNP operations would be standard procedure at high altitude. By 2015, aircraft operating into 35 major U.S. airports will be required to have RNAV, and those flying above Flight Level 290 will be required to maintain RNP 2.0 (within 2 nautical miles of flight track with 95% confidence). By 2025, RNAV would be required everywhere and RNP in busy airspace. The rule-making process for these mandates is expected to begin in 2008.

By 2025, the goal of performance-based navigation would be attained and the navigation transformation to the NGATS would be complete. The FAA cannot wait until 2025 to throw the "off" switch on the ground-based navaids in favor of satellite navigation, RNAV and RNP. To reach 2025, many of the existing ground-based navaids would need to be recapitalized at a significant cost to both the FAA and the users. The FAA has already begun turning off non-directional beacons. In 2007, the FAA expects to make a decision on how many VORs to retain as a backup to GPS for en route navigation and limited support for approach and landing. A decision will also be needed on how to adjust DME coverage to provide backup for aircraft that use inertial navigation. By 2015, the FAA will be facing a decision on whether or not to shut down all it's VORs, eliminating them as a backup. By 2008, the agency would like to decide what would replace the ILSs with shut-offs beginning as

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[6] Performance-Based Operations Aviation Rulemaking Committee, *Roadmap for Performance-Based Navigation*, July, 2006

early as 2012. The problem with the VOR situation is that a backup appears to be needed only until 2015, but there are no improvements planned in GPS that would prevent a denial of service attack for civil aviation.

Avionics Equipage

The aviation community faces an equipage challenge. No users want to carry a new backup avionics system, preferring to use existing avionics. Yet the FAA cannot continue to support the current infrastructure and mix of navigational aids. There is consensus on using both ground-based infrastructure and on-board, existing avionics for backup. This accommodation with the users to not consider a more elegant transition to provide an RNAV backup to the satellite-based navigation delivering RNAV and RNP capabilities is over the politics of disinvestment in existing navigation capabilities. If a backup for satellite navigation is needed to address intentional interference, then this backup will be needed well past 2025, and there are 6 to 8 years to attain the right equipage on the aircraft and make changes to ground-based navaid infrastructure.

Loran C Not Acceptable in 2002

In 2002, the FAA realized that an RNAV backup to satellite navigation might be possible with Loran C. But Loran's future was dependent on overcoming obstacles. The existing Loran-C receivers used in aviation were not capable of meeting the expected requirements for minimum operational performance. Technical and economic issues continued to be obstacles to attaining adequate performance and acceptance of the technology for a non-precision approach. These obstacles included:

- Precipitation static (p-static)
- Hazardously Misleading Information (HMI)
    - Cycle slip
    - Additional secondary factor bias errors due to signal propagation
- Availability shortfalls
- Coverage shortfalls
- Declining customer base

Any new configuration of Loran would need to not only overcome these obstacles, but also meet operational requirements to provide an RNAV capability and a non-precision approach and landing capability equivalent to RNP 0.3. If Loran could clear its obstacles and achieve RNP 0.3, it could significantly accelerate decommissioning of VORs and would result in no minimum operating network. If air carriers and business aviation also integrated Loran for position update for inertial systems, then the number of DMEs could be significantly reduced. The problem is that no avionics standards exist for a new Loran, manufacturers would need to integrate Loran into a combined GPS/WAAS/Loran configuration (as the marine industry is doing), and there would need to be an extended period of equipage. Unlike with NDB, ILS, VOR, and military TACAN, Loran adds a new element (just like GPS): very high-quality precise timing capabilities tied to Coordinated Universal Time (UTC). Within the section on Loran Update, this paper discusses the utility of precise time along with position and navigation, for the full complement of PNT.

Current Aircraft Equipage

The reality is that even the existing aircraft fleet is not equipped to transition to RNAV/RNP. Approximately 85% of aircraft that fly into airports with RNAV approaches and departures have the necessary equipment to fly the procedures. However, only about 30% of these aircraft have the equipment and training necessary to conduct RNP operations. Approximately 63% of general aviation has GPS and this is not augmented with WAAS. Very few air carrier aircraft carry GPS with WAAS augmentation. This means that, as an entire fleet, there will be a need to equip with some form of satellite navigation capability along with a backup strategy. Certainly, between now and 2025, there will be several cycles of aircraft navigation equipment upgrade. The immediate need is to integrate the backup strategy into GPS/WAAS and make its functions transparent to the users.

Loran Update

Loran is frequently dismissed by some of those involved in navigation as "old" or "outmoded." Nothing could be further from the truth. The problem is that few leaders in aviation have really considered Loran as a viable option for positioning and navigation and would not consider equipping knowing its history – even though eLoran is significantly different than the predecessor Loran C. This update is included to educate the aviation community on how Loran has transformed itself and why it is a viable candidate to backup GPS.

Enhanced Loran is not the Loran-C of the past
eLoran delivers a true RNAV capability in all flight phases through RNP 0.3 instrument approaches due to significant receiver design changes that treat the Loran transmitters as if they were GPS satellites on the ground.

The Congress has continuously supported infrastructure upgrades and research and development that has not only solved the obstacles to using Loran in aviation, but Loran has reinvented itself on the avionics side. This reinvention has created an RNAV capability that complements GPS and operates as if the Loran transmitting sites act just like GPS satellites, but without the vulnerabilities of interference. The system is available now; modernization of the transmitting elements are complete in the contiguous 48 United States (CONUS) and underway in Alaska, thanks to foresight and interest by Congress in preserving Loran-C services. The Loran update is discussed in terms of PNT technology – now modernized and named Enhanced Loran (eLoran).

First, there is a bigger story about eLoran, recognizing PNT positioning, navigation and timing as essential services, and to appreciate how different, and how similar, GPS and eLoran systems are. GPS and eLoran can be partners in a robust, integrated positioning, navigation and timing system-of-systems. Both are mature systems with well-known characteristics, and with updates underway.

PNT as Critical Infrastructure

Long before the events of September 11, 2001 brought the terms and concepts of "Critical Infrastructure" and its protection into sharp focus, the operating agencies of the U.S. Government, together with international standards agencies, industry and academia were concerned with the safety and reliability of those services and systems deemed important for the quality of life and safety we desire.

The systems and procedures we now refer to as "legacies" were purpose-built to serve our needs; although sometimes very narrowly defined domain need. Technology has given us a more transcendental service; for example, in this paper we refer frequently to the Global Positioning System. This provider of PNT services has become a ubiquitous commodity in its relatively short civilian lifetime, offering safety, utility and convenience unheard-of only a short time ago. Its use goes well beyond aviation and military applications, providing our nation’s citizens with services they cannot do without – it is not just "where am I and where do I go" anymore. Little wonder that the operators of critical systems and industries have adopted GPS to make things happen; little wonder that a short look backward has us asking, "How did we ever get along without the benefits of GPS?"

Transportation and communications hold keystone positions on the Nation's list of essential activities. Almost every identified critical infrastructure depends on transportation of goods or communication of information. And both of these depend on PNT services, with heavy dependence on GPS.

The U.S. President's 2004 policy directive on PNT clearly identifies GPS as itself a critical infrastructure -- because of the cascading economic, convenience and safety effects of its degradation or loss. GPS is a high-value target for that very reason. Protection against the effects of the degradation or loss of PNT against natural hazards and man-made dangers is a high-value priority. Therefore, reduction of the target value of GPS, and protection against natural anomalies that impact performance are themselves high-value priorities.

eLoran can serve the PNT functions that GPS provides, with less precision in positioning and navigation but no less safety. Its signals cover our nation, and the strong signals are difficult to jam. Unlike GPS, eLoran signals penetrate inside buildings, under foliage and can support navigation in urban "canyons" where GPS is often masked by buildings. Use of eLoran allows continued operation of transportation and communications in the absence or degradation of GPS and thereby reduces the target value of GPS, providing security and sustained economic viability at reasonable cost.

eLoran offers supporting PNT to additional aviation capabilities like the Automatic Dependent Surveillance System – Broadcast (ADS-B) that is discussed in the section of this paper on surveillance.

On the political side of eLoran, there is broad support for continuing the sustainment of the Loran system.

The Aircraft Owners and Pilots Association (AOPA) endorsed continued operation of eLoran. AOPA supports the ADS-B concept, and use of eLoran could allow reduced expenditures, delaying or reducing the threat of aviation user fees and impact on its members. The Airline Transport Association (ATA) predicates support for eLoran on acquisition and deployment strategy, emphasizing equipage, benefits and costs.

The networks and the timing community and cell phone industry have been purchasing Loran receivers for many years, as a backup to GPS and local-clock timing for synchronization of high-speed communications. Due to the uncertainty of continuing Loran by the Government, most cellular providers use crystal oscillators to provide up to 24 hours of backup. But in the 2005 GPS Jamfest, cellular phone coverage was lost in the area of jamming within a few hours. Military test range commanders report a need for Loran continuation for timing backup systems.

The low frequency and high power characteristics of eLoran, makes the system able to penetrate buildings, ground and water -- unlike GPS. Technical work continues in this area, by military and civilian organizations. There is promise in integrating positioning service improvements in tunnels and near built-up areas where GPS is masked. When these trains and motor vehicles emerge from areas without GPS coverage to areas in GPS coverage, the transition can be transparent to the user.

Loran and GPS Compared

New all-in-view receivers treat loran transmitters as if they were GPS transmitters on the ground in fixed positions.

A number of studies have compared Loran and GPS, with the conclusion that the two are partners in a complementary PNT service. Their similarities lead to efficient integrated receiver designs. Their dissimilarities avoid simultaneous effects from natural causes and make a comprehensive attack on the Nation's PNT capabilities far more complex and difficult. Further, the capabilities of Loran permit extension of some PNT services into areas where physics will not allow GPS to serve. Table 1 provides an outline. See the section of this paper on "Creation, Demonstration and Application of eLoran" for more detail.

Table 1: eLoran and GPS characteristics compared[7]

Parameter	eLoran	GPS
Frequency	100 kHz	1.2-1.5 GHz
Propagation	Groundwave	Line of Sight
Chief Propagation Errors	Conductivity, troposphere variations*	Iono delay variations*
Penetration	Walls, ground, ~6' seawater	Very little penetration
Modulation	Time Division + Code Division	Spread spectrum CD
Coverage	To ground level and below	To ground level
Signal Strength	Relatively high	Very low by design
Timing Basis	Triple Cesium	Rubidium, some Cesium **
Tx Location	Ground - stationary	Space - moving
Utility: Marine example***	Open water; harbor ops.	Open water; harbor ops.
Utility: Aviation example	En route, terminal airspace LNAV, derived VNAV; RNP 0.3 approach****	En route, terminal airspace LNAV / VNAV
User communities	Multiple (air, land, marine)	Multiple (air, land, marine)

* Propagation errors are affected at different times and places by components of solar storms; GPS propagation variations are not correlated with Loran propagation variations.
** in 2004
*** Differential operation: 8.7 meters @ 95%, reported May 2006 by General Lighthouse Authorities of the United Kingdom and Ireland, The Netherlands
**** Vertical-guided "precision" approaches require GPS plus WAAS/LAAS/JPALS augmentations.

Table 2 is taken from a presentation to the DOT by the Lighthouse Authorities of the United Kingdom and Ireland. It has been used here to emphasize that there is considerable European interest in eLoran combined with the expected capabilities of Galileo, their equivalent satellite constellation to GPS. The

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[7] Lilley, Robert, "The Loran-C Augmentation / Alternative for Critical Positioning, Navigation and Precise Timing Applications," Briefing for Office of Science and Technology Policy, Executive Office of the President, Washington, DC, July 9, 2003

comparisons are equally valid in the U.S. and extend to the aviation community as well. eLoran is shown to be the only system providing fully independent services to the multiple PNT user communities. The World will use the combined performance of GPS and Galileo for PNT.

Table 2: eLoran and Other Systems Compared as to Services Offered. [8]

A second, complementary and dissimilar, multi-modal independent PNT[1] service is needed to realise the full benefits of e-Navigation and to deliver the radionavigation dividend to users

Service	Independent PNT	Multi-modal	Independent with respect to GPS		
			System	Signal	User
Galileo	✓	✓	✓	×	×
eLoran	✓	✓	✓	✓	✓
DGPS	×	✓	×	✓	×
WAAS[3]	× ✓	✓	× ✓	×	×
Radar[2]	×	×	✓	✓	✓

- Marine navigation and surveillance need a mixture of positioning and timing systems
- A single source of positioning and timing is unacceptable in the marine domain
- *eLoran* is the only service that fulfills the requirement

1. PNT – Position, Navigation, and Time
2. Including radar transponders – Racons
3. WAAS has independent time, but not P or N

17 March 2006 1

With the concept of PNT and critical infrastructure discussed, the next section documents the history and evolution of Loran.

History of Loran

Although Loran standards and research began in the 1940's, the U. S. Coast Guard (USCG) brought the Loran-C system into civilian use when that agency became a part of the U.S. Department of Transportation in 1967. In 1974 the system was designated the official navigation and positioning system for the U.S. Coastal Confluence Zone, and its future appeared secure, with a million marine users plus cargo and fleet tracking systems under development.

The FAA responded to general aviation pilot interest in Loran-C as early as the mid-1970s. Informally, various operators had demonstrated the utility of Loran-C navigation in the cockpit, using hardware intended for marine use. The FAA's Loran-C program in a short time had demonstrated that Loran-C,

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[8] Basker, Sally, "The Future Role of eLoran for e-Navigation," Presentation to U.S. DOT, 17 March, 2006.

where coverage existed, offered a useful wide-area navigation capability. Navigational accuracy was determined to be suitable for en-route and terminal-area operations in specific Loran-C coverage areas on both coasts and in the Gulf of Mexico.

The Radio Technical Commission for Aeronautics (RTCA) produced a consensus-based Minimum Operational Performance Standards document (MOPS; DO-194), and manufacturers produced avionics that offered affordable new in-flight information in the full range of general aviation cockpits. For the first time, accurate digital distance-to-go and time-to go were available at low cost – to fully flexible, geodetically defined waypoints. Basic flight planning, fuel-burn computations, cockpit workload and other factors were enhanced by this relatively low-cost addition to the instrument panel.

Almost immediately, the aviation community adopted the system, with more than 100,000 units installed shortly after introduction. Both pilots and air traffic control personnel learned new modes of cooperation, to take advantage of this newfound independence from Victor Airways and VOR and DME ground-station locations. There was widespread talk of shutting down VORs and saving money. It did not happen, partly because Loran-C was not yet ready to replace the VOR or VOR/DME approach procedures, and because CONUS coverage was incomplete.

The FAA approved use of the Loran-C in the 1980s for flying in visual and instrument weather in en route and terminal-area airspace. Instrument approaches using Loran-C were deferred, pending improvements to the system's availability and continuity of service. It was becoming clear to the Loran community that to meet instrument approach requirements, changes would be necessary in the airplane (receiver architecture, antenna modifications to limit static caused by precipitation known as p-static) and on the ground (solid-state transmitters throughout the system, fast-changeover to standby transmitters, better timing and automated monitoring of signal quality). It was also clear that these changes would benefit all users, not just aviation. However, without a firm commitment for continued system operation, industry investment in the new technology for the avionics was difficult.

Due partly to the obvious popularity and widespread use of the system, and to initial encouragement from the Congress, it was decided to extend coverage from the coastline into the interior, to fill the "Mid-Continent Gap." Four new transmitters were installed and interconnected with the original Loran-C sites. Joint support was and is provided by the USCG and the FAA, who where then both part of the U.S. Department of Transportation (DOT). The "Mid-Continent Loran-C Chains" were activated in 1991.

The FAA at that time was just announcing results of the Loran-C "Early Implementation Program" during which the system's ability to support non-precision (lateral-guidance-only) instrument approaches, similar to those made possible by VORs and non-directional beacons (NDBs) was being established. The RTCA MOPS[9] were updated to include instrument approach tests and standards, and an FAA Technical Standard Order (TSO) C60b[10] was written, to provide manufacturer guidance in testing and certifying avionics units. Automated transmitter monitoring methods were designed and tested, special-use approach procedures and flight-inspection criteria were developed, and a

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[9] RTCA Document DO-194, RTCA, Inc, Washington, DC. November, 1976

[10] http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgtso.nsf

nationwide monitor network was installed to generate data for wide-area corrections to account for propagation variations.

Although the system met accuracy standards, and its performance "fit" within the previously-defined boundaries of protected airspace (See FAA Advisory Circular 90-45A[11]), the certification flight testing for one of the first receivers designed to TSO standards revealed continuity deficiencies when operated in instrument-approach mode.

The short version of events that followed is that the aviation instrument approaches *as defined at the time for Loran-C*[12] were used by holders of FAA Letters of Authorization, but were only released for public use for a short period. The public approaches were taken out of service by an FAA Notice to Airmen (NOTAM) pending further tests and the installation of an "automatic blink system" (ABS) transmitter warning monitor, to guarantee a cockpit flag if pulse timing exceeded an established tolerance. ABS was installed, later, as one of the early moves toward eLoran.

The years following the Early Implementation Program began the era of civilian GPS. Upon its partial release to the public[13] following the 1983 loss of Korea Airlines Flight 007, the Military's NAVSTAR Global Positioning System quickly demonstrated that it could support en route and terminal operations plus non-precision approaches, even with 100-meter accuracy limitations then imposed by the GPS Selective Availability (SA) function. AOPA recommended GPS to its general aviation members, but also recommended that Loran be retained in the cockpit as backup, even as next-generation navigational systems become available.[14]

With SA reduced to zero in 2000 and the subsequent FAA WAAS accuracy and integrity augmentations in place, GPS now enables more advanced instrument approaches with vertical guidance and lower minimum altitudes in service to the National Airspace System. System performance characterization was modernized, by development of performance: *accuracy, availability, continuity and integrity*.

Together with *coverage*, these factors describe required performance of the combination of onboard and space-based infrastructure for aircraft PNT systems within the larger framework of airspace characterization defined by FAA's Required Navigational Performance methodology.
To the present day, Loran continues as a viable system for aviation in en route and terminal-area flight. Timing receivers are sold for backup in the cellular telephone industry, and the precise time transfer available from the system finds application in intentional high-interference environments such as test-range operations. In the marine community, historical reference locations originally recorded in Loran-

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[11] http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf

[12] Initially, each Loran-C approach procedure was restricted to a single, specific transmitter triad, using time-difference of arrival measurements. Only a few receivers were approved, after modifications and testing for integrity. Approaches were approved only at airports where (temporary) go/no-go monitors were installed. All-in-view receivers were not used.

[13] Pace, Scott, et. al.; *The Global Positioning System: Assessing National Policies,* Rand Corp., Santa Monica, CA, 1995, Appendix B.

[14] AOPA Air Safety Foundation, "GPS/Loran: A Guide to Modern Navigation," Frederick, MD, 1995.

C time coordinates offered better repeatable accuracy (until GPS SA was turned to zero) than did GPS (for revisiting a prime fishing location, for example.). More recently, a newly marketed GPS/WAAS/Loran integrated receiver is popular among marine users. Recognition of the advantages of low-frequency signal penetration of buildings, earth and water resulted in study and application to cargo tagging.

Starting in 1997 The U.S. Congress began explicitly supporting evaluation and modernization of the Loran-C system, with project team management vested in the FAA. Over the decade that has followed, the FAA/USCG evaluation and modernization program has received some $160-million in continuous support – a clear Congressional direction, backed up by unmistakable committee and conference language. In 1999, The FAA Administrator announced that the agency would "…always have a backup navigation system on the ground."[15]

The year 2001 was a turning point for a variety of reasons. On September 10, the US DOT Volpe National Transportation Systems Center released the GPS Vulnerability Assessment[16], which identified PNT as a critical infrastructure element and stated that a backup to satellite systems was needed for that reason. Volpe recognized that the FAA was undertaking studies of a modernized Loran-C system as a possible complement to GPS, and stated that if Loran were determined to have a role in the navigation mix, the US DOT should promptly announce this fact and encourage the deployment of the new Loran technologies then emerging.

The DOT instructed the FAA and the USCG to respond to the Volpe GPS Vulnerability Report so that a decision on GPS backup could be made. The Congressionally-supported FAA/USCG Loran evaluation and modernization work continued, and the Volpe Center prepared a Loran-C benefit/cost analysis. The FAA reported on its PNT strategy on several occasions, but the companion report from the USCG was never released outside the government, and Coast Guard objections to the highly-positive Loran benefit/cost report also prevented its release.

The 2001 Federal Radio-navigation Plan remained relatively opaque on the subject of Loran-C, stating only that the system would be operated in the short term while the Administration evaluates the long-term need for the system. (Short-term and long-term are not defined, but the statement came to be widely regarded as a promise to run the system through 2008, because of a statement to that effect in the report of the DOT POS/NAV Radio-navigation Systems Task Force, which reported out in 2004.)

The FAA reported in 2002 that its backup studies were progressing and implied that the Loran-C enhancements being deployed would, if successful, result in enhanced-Loran being "the best" backup/alternative to GPS for aviation. The studies included such factors as system performance, expected cost savings by reducing dependence on legacy navigational aids, and the fact that Loran was multi-modal – could be shared among a variety of user communities as was GPS – where the legacy navaids could not.

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[15] Address by FAA Administrator Jane Garvey at ATCA Glen Gilbert Award Dinner, San Diego, November, 1999.

[16] John A. Volpe Transportation Systems Center, "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System," August 2001.

Later in 2002, the FAA released its Navigation and Landing Transition Strategy that provided a specific roadmap to National Airspace System performance increases through heavy reliance on GPS for navigation and other uses. It set forth specific criteria that a system such as enhanced Loran must meet in order to preserve NAS safety in the absence of GPS services. Enhanced Loran – eLoran – now had specific performance requirements to meet. The eLoran team reported progress in public meetings such as the U.S. Institute of Navigation and the International Loran Association, and at similar technical venues throughout the world.

Meanwhile, the U.S. Coast Guard moved from the Department of Transportation to the Department of Homeland Security in March 2003. The report from the USCG to the DOT on marine use of Loran-C was never released outside the government.

In March 2004, the FAA-led Loran Evaluation and Modernization Team announced that all the criteria in the FAA Navigation and Landing Transition Strategy had been met. All-in-view receiver technology similar to GPS designs, the use of magnetic-loop antennas, which reduced noise due to p-static to manageable levels, and the modernized ground installations not only could meet the stated aviation requirements, but also the more restrictive marine requirements added during the study. In fact, the aviation requirements had been tightened due to the FAA's move toward Required Navigation Performance, and eLoran could meet those requirements also.

eLoran has become not just the *theoretical* best complement to GPS for aviation, but is now *the most technically capable backup system, delivering an RNAV backup for an RNAV future, meeting RNP 0.3 approach requirements and moving closer to GPS avionics to better support an integrated GPS/WAAS/eLoran avionics system.*

GPS – Increased Dependence Increases Target Value

The GPS Task Force of the Defense Science Board, in advice to the DOD,[17] calls for changes in GPS for the future that will inevitably attract more civilian dependence on the system in critical applications. The report also includes warnings related to the current health of the GPS constellation and the ground control segment calling for more satellites and ground system rehabilitation.

"GPS-III" is being defined[18] – there are additional civil frequencies and plans for accuracy, availability, integrity and continuity advances that will enhance civil services and raise popularity among service providers, after-market designers and their user/customers. The U.S. economy and quality of life will both benefit from the additional services made available. However, the price to be paid is measured in increased dependence on GPS as the primary PNT provider even beyond today's widespread applications.

At the same time, the FAA has announced a decision to extend GPS/WAAS-based instrument approaches to 200-foot decision height above touchdown. This performance closely matches the capabilities of Category I ILS, the standard legacy system in use for precision landing.

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[17] Defense Science Board, "The Future of the Global Positioning System," released November 22, 2005. See www.acq.osd.mil/dsb/reports/2005-10-GPS_Report_Final.pdf

[18] GlobalSecurity.org, "GPS III / GPS Block III," http://www.globalsecurity.org/space/systems/gps_3.htm

> *"WAAS moves us another step closer to a satellite-based airspace system," said FAA Administrator Marion C. Blakey. "Less reliance on a ground-based infrastructure will result in improved safety, including enhanced approach and landing operations in marginal weather."*[19]

There quite naturally will be pressure to decommission some ILSs, once again increasing GPS dependence in a safety-critical application.

Beyond aviation, the growth in uses for GPS are phenomenal, with widespread applications in communications, agriculture, power management, and natural resources. As use and dependency increases across broader segments of our economy, the value of GPS as a target (in absence of backups) escalates.

GPS Interference

GPS interference comes in many forms: 1) unintentional interference, caused in close proximity of the receiver from nearby sources, 2) unintentional interference caused by negligence or as collateral damage from deliberate testing, 3) solar effects, and 4) intentional interference, whether terrorism or other nefarious purpose. Experience has shown that any of these is possible, to the extent that they can impact safety, capacity and our economy. Whether you personally believe it is necessary to provide a backup or not, there is a requirement to protect PNT as a critical national infrastructure as a matter of national policy. The fact that so far no direct attacks have occurred in the United States, not due to the complexity of the task, but to the low level of impact to aviation in today's redundant coverage from ground-based navaids.

Unintentional Interference

A GPS "failure" does not have to be the result of terrorist act or nature. For the individual user, use and safety may be affected by loss of on-board PNT services due to interference from other radio systems on the aircraft (local oscillators have been known to jam GPS receivers) or nearby. A notorious case involved a TV antenna preamplifier that malfunctioned and jammed a West Coast harbor for many months. The effect for an aviator can be the same as loss of GPS overall - No cockpit navigation data - no position transmissions to other aircraft or controllers (See ADS-B, later in this report) unless a complementary backup system is part of an integrated PNT system solution. For a mariner, similar problems occur with onboard navigation and with AIS monitoring.

The US Navy has also reported occurrences of GPS antenna failures in proximity to high-power radar from nearby ships.[20]

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[19] Federal Aviation Administration, "FAA Announces Major Milestone for Wide Area Augmentation System (WAAS)," Release No. AOC 05-06, March 24, 2006.

[20] Williams, Stanley F., "GPS Vulnerable to Microwaves," *GPS World*, April 1, 2006.

In 1993, during the latter days of the Loran-C Early Implementation Program and the developmental days of civilian GPS use, the U.S. Department of Transportation published an "Introduction and User Guide" for Loran-C. In the section titled "Loran in the Future of Aviation," the following words appear:

> *"Loran will be available for use by civil aviation well into the next century. ... There will be an operational benefit from the Loran/GPS combination. Neither Loran nor GPS is acceptable, alone, as the sole source of navigation for an aircraft operating the en-route phase of flight in the [National Airspace System (NAS)]. Both systems can experience loss of signal coverage over large geographic areas, and such a loss would affect hundreds of aircraft at the same time. Together, however, the two systems provide enough redundant signal sources to serve as a sole means of en-route navigation."* [21]

The details may be slightly dated, but the wide-area effects concept is very modern. Exactly such an outage is described in Notices to Airmen (NOTAMs) issued for February 7, 2006, evidently for a military test transmission from an offshore position near the Virginia Coast:

> **Boston Center (Nashua NH) [ZBW]:** February NOTAM #16 issued by GPS Notam OA [GPS]
>
> GPS is unreliable and may be unavailable within a 267 nautical miles radius of 365000N/0753300W at FL400, decreasing in area with a decrease in altitude to 221 nautical miles radius at FL250, 153 nautical miles at FL100, and 110 nautical miles at 4000 ft. above ground level. The test area IMPACTS the Boston, New York, Washington, Atlanta, Jacksonville Air Route Traffic Control Center (ARTCC) airspace, and the new York oceanic FIR. Effective from February 07th, 2006 at 07:00 PM EST (0602080000) - February 07th, 2006 at 10:00 PM EST (0602080300)

NOTAMs for the same event were issued for Boston, New York, Washington, Atlanta and Jacksonville ARTCCs, plus the New York Flight Information Region for overseas flights for three such outages on February 7, 2006, 7-10 AM and 2-5PM Eastern Time, and February 8 from 9 AM to noon.

Such outage warnings maintain the *integrity* of the GPS services by warning users of potential degradation or denial. However, the *accuracy*, *availability* and *continuity* are certainly suspect during these times, over the entire U.S. East Coast. This real-world example is neither the result of a terrorist plot nor natural disaster. This outage, whether for training or test, is still very real to providers and users of the affected infrastructure. The inexpensive eLoran alternative fills this performance gap, as projected in the 1993 Volpe Center publication.

These examples are a bellwether for the future – GPS/GNSS interference events will continue, just like with other navigational aids, radio communications, and even radar. But as PNT is consolidated into one technology like GPS, then require GPS to do more (like RNP), and your entire airspace structure in the future is built around 4-D trajectory-based separation with precision performance to accommodate aircraft traffic growth, the stakes go up for integrity, availability and continuity of service.

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[21] U.S. Department of Transportation, "Loran-C: An Introduction and User Guide," Center for Navigation, Volpe National Transportation Systems Center, Cambridge, MA, February, 1993.

Solar Weather Effects

The current 11-year solar cycle peaks in 2010-2011, [22] and predictions are for activity on a scale similar to 1958, when the Aurora Borealis was visible as far south as Mexico. In the solar storm of October 2003, thanks to warnings from NOAA's Solar-observing (SOHO) spacecraft, there was time to protect the control systems for electrical power grids, and place some satellites in safe modes. GPS performed to its civil specification,[23] but effects on the FAA WAAS GPS augmentation system were felt, with a notable example being loss of near-precision approach capability for a number of hours. WAAS researchers are modifying system software to adapt to solar storm effects while maintaining the performance margins required for this safety-of-life system. However, NASA and NOAA space weather forecasters[24,25] place good confidence on the predictions of very strong storms in the current solar cycle.

The significance of the solar storm information is that the use of complementary systems with widely separated frequencies and different propagation paths offers added availability and continuity of PNT services during such storms. The solar effects do not occur in the same places at the same times for GPS as they do for eLoran since Loran travels as a ground wave inside the ionosphere.

<u>But could it really happen?</u>

There is no difference between interference and computer network hacking or probing Government networks for possible cyber-war applications. For now, it is prudent to protect the critical PNT infrastructure and let the users of the NAS determine whether they could weather an attack or whether they should carry a backup. The Government's responsibility is to provide for protection, and in this case, intelligence, interdiction, and apprehension will not suffice to prevent serious economic loss.

Intentional Interference

The Volpe Report on GPS vulnerability summarizes quite well the intentional threats to satellite navigation. The signal characteristics of GPS make interference over a large area fairly simple. A piece of test equipment called a signal generator can be used. Existing radio frequency oscillators can be modified; even cell phones can be altered to interfere with GPS. A signal generator on a test bed caused significant, widespread outages in the Phoenix, Arizona area in 2002.

The most common scenarios include depositing multiple jammers that would subsequently be found by the authorities. Another is an airborne jammer, either by balloon or an aircraft, the greater the altitude, the greater the interference area. Probably the most troubling would be the mobile, intermittent jammer, turned on long enough to disrupt airport and terminal operations, then turned off and moved to a different location. This compounds tracking and apprehension of the culprit. In absence of

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22 Niles, Russ, "Solar Storm Coming – In Five Years," www.AvWeb.com, March 13, 2006.

23 NSTB/WAAS T&E Team, "Performance Analysis Report", Report #44, 1 October – 31 December 2003, William J. Hughes Technical Center, ACB 430, Atlantic City, NJ., January 31, 2004

24 http://science.nasa.gov/headlines/y2006/10mar_stormwarning.htm?friend

25 Personal communication with Joseph Kunches, Sec'y for Space Weather, Int'l Space Environment Service and Chief, Forecast and Analysis Branch, NOAA Space Environment Center, Boulder, CO.

meeting all of the operational requirements defined earlier, the safety, capacity and economic impacts would be significant.

The target value for nefarious acts increases in proportion to the dependency on the GPS technology not only for aviation, but also for the economy as a whole. This is where a backup provides the best deterrence – if services are not disrupted due to the backup being in place, the value of the original target – jamming GPS is highly diminished. In addition, by comparing the backup to the GPS solution can defeat spoofing.

Human Errors

Operators of the GPS constellation can make errors, software changes can be defective, and up-link stations can experience equipment failures or operator errors. These types of disruption are controlled by policies and procedures to minimize their occurrence. Human errors on the operations side of GPS are not considered a significant enough risk to, in themselves, warrant a backup.

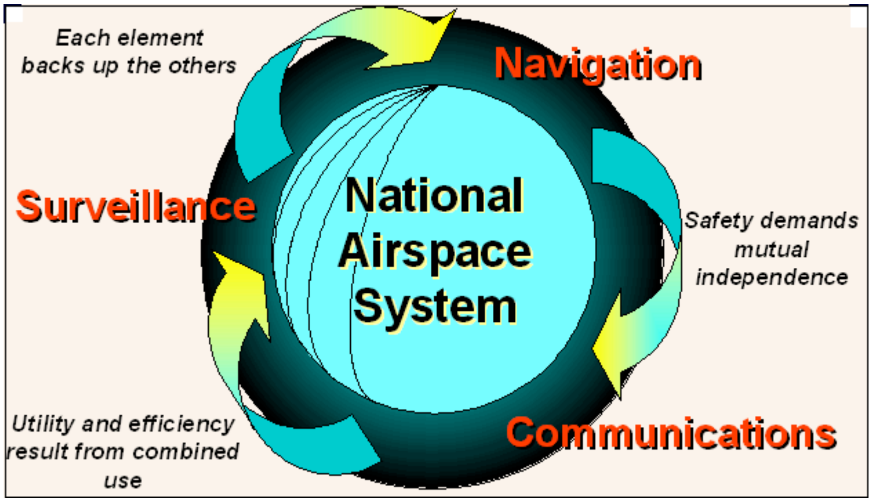
Automatic Dependent Surveillance - Broadcast

The FAA and the aviation community are on a path to replace existing ground-based surveillance (primary radar and secondary beacon surveillance (transponders) with Automatic Dependent Surveillance-Broadcast (ADS-B) as a source of major cost savings and improved surveillance performance.[26] ADS-B uses position broadcasts from aircraft to deliver to the air traffic controller the aircraft position and intent. Precision location is based on GPS. While ADS-B provides equivalent or better surveillance for separation, this same broadcast of position and intent can be used air-to-air to improve situational awareness. Avionics are envisioned that use ADS-B broadcasts to enhance sense-and-avoid operations, a likely requirement for allowing unmanned aerial vehicles to operate in the NAS, and provide both capacity and safety advantages. Ultimately, ADS-B is expected to allow a reduction in NAS reliance on expensive active radar technology while retaining or increasing the levels of safety and utility of the airspace.

Automated Dependent Surveillance – Broadcast The aircraft determines its position from navigation and automatically broadcasts to air traffic control and other aircraft its position every second. Intent information is also provided. If GPS is used for positioning without a backup capability, surveillance is lost along with navigation with interference.

The problem is that for the entire history of flying in weather, the three pillars of aviation safety have been communications, navigation and surveillance (CNS), but always as independent functions that could back up the failure of one of the other pillars. If the pilot lost navigation, surveillance would provide radar vectors. If communications was lost, the pilot was expected to follow the flight plan through navigation and the controller would use surveillance to keep the airspace clear. If surveillance were lost, navigation and communication would be used with position reporting.

[26] See, for example, Hughes, David, "Coast-to-Coast ADS-B," Aviation Week and Space Technology, November 7, 2005.



ADS-B crosses over the independence of the three pillars and now there will be a dependency between navigation and surveillance. With ADS-B, if the navigation solution (the aircraft's position) is unavailable, ADS-B will broadcast no position information from the aircraft. While more advanced air carrier aircraft and business aviation will be able to substitute an inertial position for the GPS position, the inertial system will precess without update and over time, the position will become less reliable.

There are multiple ways to look at the loss of ADS-B precision position reporting. From the aircraft's perspective, you can either provide a position report derived from a different navigation source like eLoran or the flight management system, or you can revert to procedural separation and position reporting. While either would provide safe separation, it would seriously impact system capacity by reverting to procedural separation in the absence of another on-board source of positioning. From the ground, there are more options. Transponders and secondary surveillance radar could be retained (necessitating aircraft to continue to support transponders and ADS-B). This is an expensive alternative and perpetuates continued support for radar technology that is not needed for air traffic control. By providing an independent source of position information, the ADS-B continues to function in the presence of GPS interference.

The FAA could invest in multilateration, a process where even if the aircraft were not reporting its position, ground stations would measure time of arrival of the ADS-B broadcast with the missing data, and through time synchronization, determine aircraft position. This is a mature technology and is used in terminal airspace in Innsbruck, Austria and on many airports. While terminal use of multilateration is the equivalent of air traffic control beacon interrogation, En route coverage to the equivalent of today's significantly redundant primary and secondary radar coverage would add approximately 1/3rd to the cost of an ADS-B network of ground stations. Multilateration uses the same ground infrastructure as ADS-B.

A not too well publicized benefit of multilateration is independent verification of the ADS-B position provided by the aircraft. This benefit addresses the threat of spoofing – generating targets for the air

Multilateration

Measures the time of arrival of a signal from an aircraft to multiple ground receivers and from the time of arrival position of the aircraft is derived. Multilateration does not require the content of the position derived from navigation. It just needs the emission from the aircraft.

traffic controller and pilots to confuse or obscure some other act. Spoofing is not an immediate issue since there will still be primary and secondary radar during the transition to ADS-B. The ADS-B output from the aircraft is neither encrypted nor authenticated. As ADS-B becomes the sole means of surveillance for air traffic control, spoofing becomes a viable threat. Multilateration provides the ability to verify the position of the transmission and using the ADS-B rebroadcast function of the proposed implementation, aircraft could be advised to the location of a spoofed false aircraft.

Another approach is to use eLoran, not only to verify position, but also to generate encryption for any form of air/ground digital communications. The FAA-led Loran Evaluation and Modernization Team is currently funding research at Stanford University on geo-encryption, where derived position is used as part of an encryption key.[27] First postulated by Dorothy Denning at Georgetown University in 1996[28], geo-encryption encodes a stream of data in such a way that it is only intelligible to somebody in a specific location – your location is your password, whether you are mobile or stationary, sending or receiving. Spoofing of an eLoran derived position is considered well beyond the ability of most hackers and much more difficult than playing back GPS derived position reports.

As the future national air transportation system transforms and becomes dependent on 4-D trajectory-based separation, there will be a need to negotiate between aircraft and ground via data link to define flight path changes and ADS-B will be used by automation for conformance monitoring. Since information to and from the aircraft will change the flight path of that aircraft, safety and security considerations will lead to authentication and encryption. What geo-encryption provides is a way to both verify position and support a uniquely defined encrypted key that is derived from geo-lock mapping or location signature.

Geo-encryption

Geo-encryption creates a "location signature" unique to the transmission and carried as a packet in the message for decoding

While originally conceived for use with differential GPS, Loran is being favored in the research at Stanford University because of the high signal power, difficulty in jamming, and the signals can penetrate buildings and other structures to allow for encryption keys to be derived at any work location.

The eLoran system offers the independent positioning and navigation source needed by ADS-B to maintain the independence of the CNS triad. By continuing eLoran operation, DOT and DHS give ADS-B the data it needs at low cost, while the DOT/FAA additionally achieves all the cost avoidance and benefits associated with decommissioning other navigation aids, and the Nation's PNT and transportation services remain the robust foundation for other critical assets and infrastructures.

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[27] See http://waas.stanford.edu/pubs/Group%20Meeting%20Talks/Geoencryption%20Authentication%20Di%20Qiu%20May%202006.pdf for an introduction to geo-encryption

[28] Dorothy Denning and Peter F. MacDoran, *Location-Based Authentication, Grounding Cyberspace for Better Security*, Computer Fraud and Security, February 1996 available on-line at http://www.cs.georgetown.edu/~denning/infosec/Grounding.txt

Loran Policy and Legislation

No other navigation aid has had less policy and more legislative action. This is because indecision on the part of previous and current administrations has left Loran straddling two Government agencies; there has been euphoria over the performance and promise of GPS; and slow realization and recognition of the need for a backup as a matter of federal policy. In order to describe the update on Loran, it is necessary to look at the policies and legislation relating to not only Loran, but also critical infrastructure protection. The lack of clear policy leads to greater cost for navigation. An example is the lack of policy on the ILS. In the absence of good federal policy on establishment of ILSs, the Congress has earmarked a considerable number of locations over the years to where today, the FAA is maintaining a significant number of installations where the benefit is marginal and the annual cost is growing.

Starting in 1997 with the President's Commission on Critical Infrastructure Protection's recommendations, President Clinton issued Presidential Decision Directive 63, which addressed protecting America's critical infrastructure. The Bush administration has followed suit to include protection of information technology and directed federal agencies to protect critical infrastructure. The U.S. Department of Homeland Security developed and the President signed Homeland Security Presidential Directive 7 incorporating provisions in the Homeland Security Act of 2002.

National Policy, Departmental Responsibilities

On September 11, 2001 we saw the need for reliable safety, security and social support networks and services. Almost exactly four years later, the even more widespread devastation by hurricanes on the U.S. Gulf Coast pointed out again the need for robust and resilient backbone infrastructures to protect the public health and well-being. These events show the effects of cascading unavailability of goods and services that are necessary or customary – at least, expected or assumed -- in the American model of governance and economics.

Hurricanes Katrina and Rita in particular offer insight into what happens when communications, transportation and public safety are all removed. Our social fabric is revealed as a rather fragile set of agreed-upon behaviors, supported by what we now call critical infrastructure. *Remove that basic foundation, and the ugly products of opportunism and desperation set in.* America's social and economic wellbeing is dependent upon certain critical infrastructures, power, water, communications, transportation, financial, and our ability to continue to provide vital Government services in the presence of disasters, whether man-made or natural. One of those vital services is PNT.

What the Law and Policies Say Regarding PNT

The "National Strategy for the Physical Protection of Critical Infrastructures and Key Assets"[29] defines thirteen[30] critical U.S. infrastructure sectors covering every aspect of our lives. Positioning,

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[29] The White House, "The National Strategy for the Physical Protection of Critical Infrastructures and Key Assets," February, 2003.

[30] Agriculture, Food, Water, Public Health, Emergency Services, Government, Defense Industrial Base, Information and Telecommunications, Energy, Transportation, Banking and Finance, Chemical Industry and Hazardous Materials, Postal and Shipping.

Navigation and Timing (PNT) services play an essential role in providing a service, producing a product or protecting some aspect of each critical sector.

> *"Critical Infrastructures are 'systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.'"*

From The USA Patriot Act, quoted in "The National Strategy for the Physical Protection of Critical Infrastructures and Key Assets," The White House, February 2003

Guiding aircraft to landings, steering responders to an emergency scene, providing precise timing for Internet and cellular telephone operations, tracking containers or hazardous cargo, measuring geologic changes – all rely on PNT as one of the cross-sector foundations for delivery of services and support to our economic engine.

Effects of the loss or degradation of our PNT capability would quickly cascade through the sectors causing increasing disruption as seconds (transportation), become minutes (emergency services), turn to hours (banking and finance), or drag on for days (postal and shipping). In absence of a backup for position, navigation and timing, degradation will have safety, security and economic impacts far in excess of the cost of provision of backup capabilities.

Systems providing PNT services are high value targets. The growth in use and dependency on GPS for PNT and the ubiquitous nature of its use increases its value and risk as critical infrastructure. This danger is at the center of recent U.S. policy. On December 8, 2004, the U.S. Space-Based Positioning, Navigation and Timing Policy was created which

> ***"…****establishes guidance and implementation actions for space-based positioning, navigation, and timing [PNT] programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes."*

U.S. Space-Based Positioning, Navigation and Timing Policy December 8, 2004 - Introduction

The policy thus recognizes the extent to which positioning, navigation and timing services such as those provided by GPS have become commodities which have permeated almost every category of our daily activities.

Underscoring the U.S. reliance on a robust PNT service, the policy states as a goal:

> *"Maintain the Global Positioning System as a component of multiple sectors of the U.S. Critical Infrastructure, consistent with Homeland Security Presidential Directive-7, Critical Infrastructure Identification, Prioritization, and Protection, dated December 17, 2003"*

U.S. Space-Based Positioning, Navigation and Timing Policy December 8, 2004 - III. Goals and Objectives

The Secretary of the Department of Homeland Security (DHS) bears considerable responsibility for the ultimate protection of critical-infrastructure PNT assets:

"The Secretary shall be responsible for coordinating the overall national effort to enhance the protection of the critical infrastructure and key resources of the United States. The Secretary shall serve as the principal Federal official to lead, integrate, and coordinate implementation of efforts among Federal departments and agencies, State and local governments, and the private sector to protect critical infrastructure and key resources."…

"The Secretary will identify, prioritize, and coordinate the protection of critical infrastructure…"…

"The Secretary shall coordinate protection activities for each of the following critical infrastructure sectors: information technology; telecommunications; chemical; transportation systems, including mass transit, aviation, maritime, ground/surface, and rail and pipeline systems; emergency services; and postal and shipping."

Homeland Security Presidential Directive/HSPD-7; December 17, 2003

There is an elegant "organization chart" inherent in the 2004 PNT policy – diversity of control and management among DOD, DOT and DHS, with a PNT Executive Committee for oversight and coordination. Each agency has other collaborative responsibilities related to the PNT service, but the specifics of system operation, performance assurance and backup are delineated and assigned in the Policy. DOC and DOS, NASA and others also have defined roles.

As excerpted from the 2004 PNT policy, Secretaries *shall:*

***DOD -** maintains and operates GPS, and act to mitigate interference worldwide for military purposes.*

***DOT -** Develop requirements for civil applications; cause PNT operations to meet or exceed international standards for marine, air and other modes. With DHS, develop, acquire, operate and maintain backups to support critical infrastructure.*

***DHS** – In coordination with Defense, Transportation, and Commerce, develop and maintain capabilities, procedures, and techniques … to ensure continuity of operations in the event that access to the Global Positioning System is disrupted or denied.*

Government Response to Policies

The DOD currently operates and maintains the GPS space constellation and ground control segments, providing continuous worldwide coverage usable by military and civil communities. DOD is presently acquiring a backup GPS ground segment to protect GPS operations in case of failure of the principal control facility in Colorado Springs, Colorado. Next-generation GPS satellites will have the capability for a period of autonomous operations when out of touch with the ground facilities. This "GPS-III" generation will also offer added aviation integrity and other enhancements, plus an alternative ground control site. In the process, the improved GPS system will offer new levels of services that will attract new user communities and greater overall dependence on the system. The DOD also routinely cooperates with user agencies and groups to mitigate interference. Military and civilian benefits due to reductions in interference are congruent.

The DOD is investigating "Signals of Opportunity" for use in challenging environments; eLoran is one such signal being considered. The agency has made no specific moves toward preserving eLoran as a signal of opportunity, but is reviewing recommendations pointing out the benefits of preserving purpose-built PNT signals around the world. The DOD recognizes the rigors, cost and diplomatic uncertainty of "borrowing" or "bringing-along" signals to supplement or supplant GPS where needed.

DOT/FAA has been a leader in enabling civil applications, evidence being the U.S. nationwide and international deployment of the Wide-Area Augmentation System (WAAS). The WAAS enhances existing GPS signals using a nationwide ground network of monitoring and measurement stations. It provides necessary accuracy, integrity assurance and minimal time-to-alarm in support of aviation operations in en-route, terminal and approach airspace.

WAAS services are rapidly becoming an assumed presence – a public commodity. The meter-level accuracy afforded by the system supports an amazing number and variety of applications. The WAAS is, however, completely dependent on the input of signals from GPS satellites. If GPS becomes unavailable, the WAAS provides no service. Geostationary WAAS satellites also provide a reliable timing source.

Loran Policy Decisions Pending

Recent work by DOT/FAA and DHS/USCG addressed in extensive detail the civil requirements for Loran as an alternative and backup system to GPS for air and marine applications. As a part of this ongoing work, the FAA reported to DOT and the public in March, 2004[31] on the suitability of the enhanced Loran or "eLoran" system as a backup/ alternative for PNT services. All of the underlying research and analyses have been reported in publications of the Institute of Navigation[32] and the International Loran Association.[33]

In August 2004, the Secretary of the DOT wrote[34] to the Wisconsin congressional delegation that the technical and the cost-benefit reports on eLoran were favorable to a decision to continue the system. He assured the delegation that a decision on continuation would be made "soon." The USCG's move to the DHS in 2003 may have delayed this decision, and DOT Secretary Norman Mineta's resignation in June 2006[35] may delay it further.

Comparing eLoran operating costs to current DOT/FAA legacy navigation aids is striking – eLoran at $27 million per year versus legacy systems at $100 million per year plus large service-life extension

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[31] Federal Aviation Administration, "Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications," March 2004.

[32] See the Institute of Navigation web site www.ion.org for proceedings and reprint availability.

[33] See the International Loran Association web site www.loran.org and contact the Operations Center for proceedings and reprint availability.

[34] Letter from DOT Secretary Norman Y. Mineta to Cong. F. James Sensenbrenner, Jr., August 19, 2004, published in *Loran Lines*, International Loran Association, October, 2004.

[35] Letter from DOT Secretary Norman Mineta to President George Bush, June 20, 2006; from *AOPA Online*, http://www.aopa.org/whatsnew/newsitems/2006/060623mineta.html

and/or replacement costs.[36] This fact is of interest to FAA's constituents,[37] who perceive lower costs as a path to avoiding or reducing user fees.

The DHS/USCG operates the National Differential GPS System (NDGPS) as an accuracy and integrity enhancement system for the GPS in marine and land applications. This system does increase the utility of the GPS, but in the absence of GPS signals it, like the DOT/FAA WAAS, offers no independent PNT service.

In contrast to the burgeoning DOD and DOT literature on defense and civil transportation uses of PNT services, including plans for alternative and backup operations, there is less available evidence of parallel activity within the DHS. The Volpe Center report on Loran benefit/cost[38] has not been released outside the government and is labeled "Official Use Only", it is said to be because of DHS and USCG concerns[39]. The document is reported to validate a highly positive benefit-cost ratio for enhanced Loran as a complement to GPS PNT services. Also unreleased is the USCG report prepared at DOT request following release of the Volpe Center's GPS Vulnerability Report.[40] (USCG at the time was a part of DOT). The authors of this paper were not able to review these documents.

We know that the Homeland Security Institute reported on a study of the criticality of precise-time services, but this study was not subjected to peer review nor was it released outside the Government. The extent to which these studies and reports are influencing DHS decision-making with respect to protection of the PNT infrastructure overall, or to eLoran specifically, remains unclear.
To its credit, the DHS/USCG is participating in the congressionally mandated FAA Loran-C evaluation and modernization program to create and document eLoran. Many papers and reports on technical and system management have been published as a part of the program mentioned above. Coast Guard personnel from Headquarters, from the Navigation Center and the Loran Support Unit have joined professionals from industry and academia to provide the opportunity for peer review of the work. The modernization program is a technical success.

The USCG described[41] a decision process at the recent meeting of the International Loran Association that is consistent with the U.S. Federal Radio-navigation Plan (FRP), which calls for a determination on the continuation of eLoran based on a decision by the Secretary of DOT after input from DOT and

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[36] DOT Radionavigation Systems Task Force, "Radionavigation Systems: A Capabilities Investment Strategy," January 2004 (Overlook Systems Technologies, Inc.).

[37] Aircraft Owners and Pilots Association, recommendations to the FAA Administrator, May 1, 2006.

[38] John A. Volpe Transportation Systems Center, Loran-C Benefit Cost report, March, 2004. Not released outside government, to date.

[39] The benefit-cost report is in use within the Government programs, however.

[40] John A. Volpe Transportation Systems Center, "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System," August, 2001.

[41] Merrill,CDR John, "U.S. Loran Decision Process," presentation to the 34th annual International Loran Association Convention and Technical Symposium, Santa Barbara, CA, October 18, 2006

reviews by the Secretary of the DHS. Further, this presentation included the various continuation options, including partnership with, or outright transfer of the system to other agencies.

The Federal Radio-navigation Plan is published approximately every two years, as a collaborative effort among the departments of Homeland Security (DHS), Defense (DOD) and Transportation (DOT). The quotation from the 2005 FRP given here clearly anticipates a DHS/DOT *joint* decision on the continuation of Loran during 2006.

> *"DOT, in coordination with DHS, will make a decision regarding the future of the Loran system by the end of 2006. If a decision is made to discontinue Loran, then at least six months notice will be provided to the public prior to the termination of the service."*

Federal Radio-navigation Plan, Section 3.1.4; 1/5/06

DHS/USCG moved to close down Loran before the end of 2006 by requesting zero dollars for operations and maintenance of the system in FY 2007. This budget request was followed in mid-2006 by a statement from DHS that Loran would be closed down "…as soon as possible." This curious move came unexpectedly, given the USCG's leadership[42] in the successful system modernization program and the stated desire by DHS/USCG constituents for continued service.

Fortunately for the future protection of the critical PNT infrastructure and the reduction of GPS's unfortunate high value target status, the DOT requested reconsideration of this closedown attempt, and the Congress stepped in with a reminder of the Secretaries' agreement in the FRP:

> *"The Coast Guard has proposed terminating the LORAN C program in the President's budget request because this system is no longer necessary for a secondary means of navigation. The Committee understands that a decision to terminate LORAN C is dependent upon agreement by the Department of Transportation, which has not yet occurred. The Committee assumes the continuation of LORAN C since this decision has not been fully coordinated within the Executive Branch."*

H.R. Report 109-476, DHS 2007 Appropriations Bill, H.R. 5441, May 25, 2006
H.R. Report 109-495, DOT 2007 Appropriations Bill, H.R. 5776, June 9, 2006

Legislative History

By 1995, the Congress had already established legislative intent with regard to continuation of Loran-C in partnership with GPS. In the Department of Transportation appropriation bill for Fiscal Year 1996, the following language appears:

> *The Committee has indicated to the FAA in past years that the agency should take full advantage of the compatibility of Loran with GPS technology so the substantial investment*

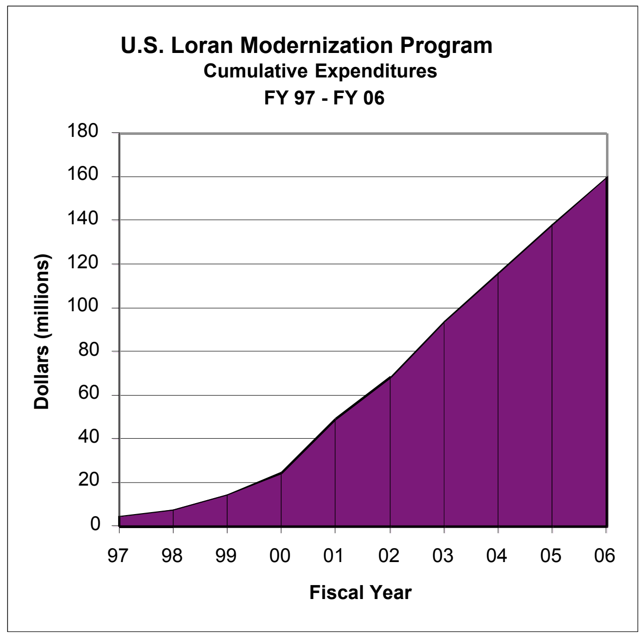
[42] Macaluso, J. J., "Loran-C Modernization," presented at 33rd International Loran Association Convention and Technical Symposium, Tokyo, Japan, October 26, 2004. [This paper is one of a series presented at the annual ILA meetings to describe progress in the modernization/recapitalization program. On June 6, 2005, Coast Guard contacts indicated that on June 10, 2005, the modernization in CONUS would be complete – with the possible exception of a later cut-over to the "time-of-transmission" control method. In the same conversation, the results of successful HEA tests of eLoran in Boston Harbor were reported. This material was also reported in *Loran Lines*, the newsletter of the International Loran Association, September, 2005.]

made by users in the technology can continue to be utilized, and so Loran can be used as a cost effective alternative system to GPS.

In view of the favorable benefits versus costs associated with Loran, and because of the substantial enhancement it provides to user safety, the Committee remains convinced that the Federal Government and users can benefit from the technology well into the next century.

The Committee believes that some funding responsibility for Loran should be transferred to the FAA. Therefore, the Committee directs the FAA to provide a plan, within 120 days of enactment of this bill, for future funding, upgrading, and support for Loran in cooperation with other elements of DOT.

Report 104-177, with H.R. 2002, July 11, 1995



With those words almost exactly ten years ago, the Congress levied foretelling requirements on the FAA. In the fiscal year that followed, the Congress began a program of support for Loran, even when not requested by the Administration, which has resulted in today's definition, re-capitalization and deployment of elements of eLoran.

The Congress has provided continuous funding for the collaborative DHS/DOT, FAA/USCG program to this day, with $160 million being provided since 1997 to enhance the Loran system, conduct research to make Loran a viable backup to GPS, and provided the investment for research that has produced eLoran. Modernization in the CONUS is complete, an additional 3 transmitters have been procured, and the FAA estimates that an additional $75 million would be needed to fully modernize Alaska. The USCG, however, estimates approximately $250 million to complete modernization and upgrades of support facilities and buildings. Resolution of differences is underway between FAA and the USCG.

In May 2005, the U.S. House of Representatives restated its support for the work between the DHS/USCG and the DOT/FAA for Loran modernization:

"*The Committee continues to support that collaborative work being accomplished under the existing interagency agreement between the two agencies and remains convinced that this joint initiative offers potential for important marine safety and security benefits, along with substantially reduced future system operations and maintenance costs.*

The Committee believes heightened attention is warranted by the Coast Guard in supporting and completing the Loran recapitalization."

Department of Homeland Security Appropriations Bill, H.R. 2360, May 17, 2005

Authorization language for the fiscal year 2007 states Congress' view that the modernization work should continue and that Loran operation should continue:

> *"There are authorized to be appropriated to the Department of Transportation, in addition to funds authorized for the Coast Guard for operation of the LORAN-C system, for capital expenses related to LORAN-C navigation infrastructure, $25,000,000 for fiscal year 2006 and $25,000,000 for fiscal year 2007. The Secretary of Transportation may transfer from the Federal Aviation Administration and other agencies of the Department funds appropriated as authorized under this section in order to reimburse the Coast Guard for related expenses."*

Conf Report on H.R. 889, Coast Guard and Maritime Transportation Act of 2006; TITLE. IV--MISCELLANEOUS SEC. 403. LORAN-C; April 6, 2006

The Secretaries of Transportation and Homeland Security clearly enjoy the support of the Congress in the matter of creating, deploying and operating eLoran as a complement to the GPS. The legislative intent and funding is there to make eLoran a viable PNT backup to GPS and future space-based enhancements of GPS. What are missing are definitive policies, standards and procedures to implement a backup strategy. The FAA and other federal agencies have laid the groundwork in strategies, plans and the 2004 PNT policy.

Ensuring continuity of operations in any complex system of systems involves protection of a variety of assets. The 2004 PNT policy emphasizes space-based infrastructure. It is important to note that without ground-based support elements (like the WAAS reference stations), existing or proposed systems cannot provide services with the necessary *integrity* to support critical requirements related to safety-of-life applications. This is the reason the GPS/WAAS system was deployed by the FAA.

In the case of PNT services, the best defense is to implement the best offense. As discussed throughout this paper, the Nation has invested in the modernization and improvement of its existing Loran-C system to produce eLoran. eLoran provides value-added PNT services in the presence of GPS (FAA ADS-B as an example). eLoran provides a robust PNT service in the event GPS signals are unavailable or are degraded.

DOT and DHS, with funding mandated by the Congress, created eLoran to meet the requirements for a GPS alternative and backup system. eLoran enables continued operations at known levels of performance in support of land, air and water transportation in the absence or reduction of space-based services.

Several factors encourage a positive decision on eLoran:

1) **Clear Congressional intent to continue the system,**
2) **Demonstrated over 10 years and continuing with industry and user interest and confidence in the system, presuming that policy uncertainty is resolved;**
3) **Transmitter and receiver technologies are known and have already been demonstrated; and**
4) **Provider- and user-friendly cost and schedule, at relatively low O&M cost and a strong possibility to further reduce cost as an integrated backup.**

Research, Demonstration and Application of eLoran

Using eLoran is like adding the 24 CONUS Cesium-controlled timing sources ("satellites on the ground" or "pseudolites") to the PNT constellation in the U.S. at very low cost. Each transmitter site represents a ground-based backup to GPS, especially with the new "all in view" technology from new receiver designs, where instead of navigating from a chain of transmitters, the user can use any transmitter from any chain for positioning and navigation. Demonstrated performance to DOT/FAA RNP 0.3 requirements qualifies eLoran to complement GPS in traditional aviation roles, and also to provide an alternative navigation/positioning function for FAA's ADS-B system. Demonstrated performance meeting USCG harbor entry requirements qualifies the system for use in entry and approach operations.

The Nation gets positioning and navigation for any mode of transportation as well as nationwide Stratum-1 timing, making a robust PNT service to complement timing available off of both the GPS constellation and the geostationary WAAS satellites when interference is not occurring.

<u>Only one of the requirements set in 2002 by FAA's Navigation and Landing Transition strategy remains unsatisfied</u>: "A decision on the long-term continuation of Loran C and support of the associated infrastructure funding." A joint DOT and DHS decision for eLoran as a permanent complement to GPS will realize the benefits of long-term investment in a robust national space-based PNT service with ground backup that addresses the vulnerabilities of interference.

A policy decision reinforcing all the work leading to improvements in Loran will be viewed positively by the international PNT community; worldwide adoption of a common complement to GNSS for PNT will enhance its value to trans-national users, and will further reduce GPS target value worldwide.

Although involvement by both the USCG and the FAA Loran-C began much earlier, we discuss the technical and evaluation aspects from the inception of the Congressionally-mandated FAA/USCG program for continuation, upgrade and evaluation of Loran-C that started with congressional language in 1995 and began funding work in 1997.

The FAA expanded its program of study, evaluation and modeling of enhancements to Loran-C, which could be applicable to a National Airspace System (NAS) support role. Three hypotheses guided the early work, which drew on the then-contemporary FAA definition of a *supplemental* navigation system:

- **Loran-C meets requirements for NAS operations including non-precision or LNAV/VNAV approach procedures.**
    - *Availability and p-static are no longer expected to be significant factors*
- **Advantages of a GPS/Loran-C combination are demonstrated in flight**
    - *Availability of horizontal navigation with integrity through approach if GPS is lost*
    - *Ability to dispatch in the absence of onboard GPS service*

- **CONUS and Alaska demonstrations show utility for continuing use of Loran**
  - *Coverage improvements for en-route navigation through non-precision approach*
  - *Augmentation of WAAS communication of GPS integrity*
  - *Loran-C communication of Loran-C integrity, timing, control information*

This cooperative FAA/USCG work produced a variety of results, on which later eLoran progress has been based. The earlier tests of magnetic-field (loop) antennas compared with then-typical electric field (whip) antennas were replicated on various aircraft types; results again showed clear benefits from the use of h-field units. Receiver outages due to airframe-generated noise (precipitation static) in flight were eliminated as a significant performance factor.

Receiver designs that process GPS-like distance[43] measurements from individual Loran transmitters were successfully tested. Coverage and reliability were improved by elimination of the requirement for selecting only transmitters from a particular "chain." This created the "all-in-view" concept for receivers.

The evolutionary improvement of propagation models gave confidence that nationwide real-time signal monitoring and publication of predicted corrections could be dropped.

Automated transmitter monitoring equipment was deployed throughout the system.

In the U.S. and in Europe, several methods were researched and demonstrated for Loran use as a communications channel for either GPS broadcast data or for Loran system corrections, timing, and integrity data.

On May 7, 2002, a public Industry Day was held in the Washington, DC area to preview the FAA Navigation and Landing Transition Strategy.[44] Since the transition strategy featured a move to satellite-based services, the briefing necessarily included discussion of the potential for interference with the new satellite signals which are, of course, much weaker than those from legacy navigation aids. The briefing emphasized backup strategies to protect the navigation service and keep it independent of the other two elements of NAS operations (communications and surveillance).

The Loran-C system was described as "theoretically the best backup for GPS" compared with reduced networks of aviation-only navaids:

- Loran RNAV (geodetic area-navigation) positioning mimics GPS RNAV positioning.
- An integrated Loran/GPS antenna exists, facilitating aircraft mounting.
- Integrated avionics packaging is a reality.
- A Loran communication path for GPS differential corrections is desirable.[45]

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[43] The frequently-used term "pseudorange" is correct here – denoting a radio-based measurement of distance in which there is a time-of-flight uncertainty which is resolved using additional measurements. The concept is the same for both GPS and eLoran.

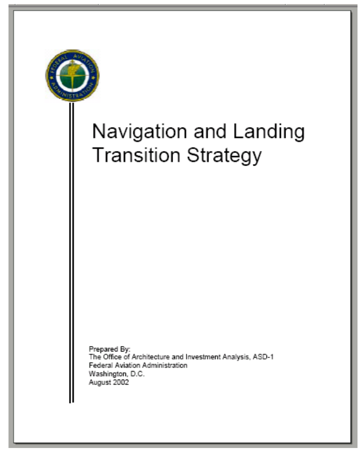
[44] "Overview of Satellite Navigation Transition," FAA Briefing for CAASD Industry Day with Users, May 7, 2002

- Coverage in mountainous terrain is needed and can be provided by Loran.

The briefing also telegraphed some elements of what would become enhanced Loran-C, or eLoran. It was implied that the system should be a primary aviation navigation aid for aviation – that users should be able to dispatch with only Loran operating on board, provided weather conditions allowed a landing with a non-precision (lateral-guidance-only) instrument approach. Loran would require an upgrade to meet RNP 0.3 to qualify as a NAS complement to GPS.

These requirements generally reflected work already in progress by FAA and the USCG in the congressional program. The RNP 0.3 requirement was the major new challenge.

The FAA Sets Requirements



Navigation and Landing Transition Strategy

Prepared By:
The Office of Architecture and Investment Analysis, ASD-1
Federal Aviation Administration
Washington, D.C.
August 2002

The FAA's Navigation Transition Strategy[46] was released in August 2002, and this publication was specific as to the thresholds an upgraded Loran-C system must meet in order to be considered for use in the NAS to complement GPS for navigation:

"The successful transition of the Loran C system from its current [2002] state to providing redundant capability to GPS is dependent upon:

- *Demonstrated performance in support of non-precision approaches*
- *Completion of work efforts to verify and improve integrity performance*
- *Reduced market risk in production of suitable avionics through the development of the necessary standards*
- *A decision on the long-term continuation of Loran C and support of the associated infrastructure funding*
- *Changes in Coast Guard policies and procedures to enhance operation of the Loran infrastructure*
- *A multimode transportation and timing user base willing to support continuation of infrastructure"*

[45] At the time, Loran was being considered as a means for carrying GPS WAAS data, to mitigate the effects of terrain blockage of WAAS geostationary satellites in some of the high-latitude areas.

[46] Federal Aviation Administration, "Navigation and Landing Transition Strategy", ASD-1, August, 2002

These aviation requirements and the USCG's marine requirements for harbor entrance and approach (HEA) became the revised baseline for eLoran**,** created by upgrading and modernizing Loran-C:

Loran-C Modernization to eLoran
Ref http://www.navcen.uscg.gov/loran/modernization.htm

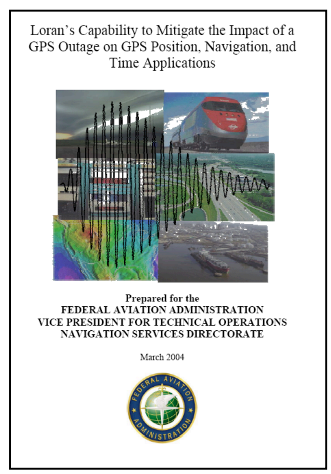
Transmitters
- Synchronization of all Master transmitting stations to UTC.
- Installation of new Cesium primary frequency standards at all stations.
- Uninterruptible Power Supplies (UPS).
- New antenna switching mechanism to reduce off-air time to 3 seconds.
- Vacuum tube transmitters replaced with solid-state equipment.
- Replace transmitter timing equipment at all stations.
- Enhance transmitter integrity monitoring.
- Target 2006 for conversion to Time of Transmission Control (TOT).*
- Add in-band eLoran communication channel – corrections, warnings.*

Receivers
- All-digital linear signal processing.
- All-in-View measurements from individual transmitters.
- Federation / Integration with GPS.
- H-field (loop) antennas.
- Integrity monitoring / alarm à la GPS RAIM / FDE.

* in progress

"eLoran Status"
Briefing for the Joint Planning and Development Office, August 1, 2005
by Aviation Management Associates

Meeting the Requirements: The FAA Report to DOT[47]



The FAA assembled a joint government/industry/professional team to evaluate and demonstrate the performance of the modernized system. Lessons learned from FAA's analysis and deployment of the WAAS were used in the formation of the Loran Integrity Performance Panel (LORIPP) and the Loran Accuracy Performance Panel (LORAPP). Past work by FAA, USCG, industry and academia was reviewed and applicable concepts were brought forward.

FAA project management recognized the DHS/DOT partnership stressed by Congress, and the importance of a comprehensive approach to Loran's partnership with GPS in critical infrastructure protection.
The team not only included the FAA requirements in the definition of eLoran, but those of the marine and timing communities as well. Team coordination and credibility

[47] Federal Aviation Administration, "Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications," March 2004.

were enhanced by frequent program review and reporting sessions, and well over 100 presentations of incremental progress and results in journals and at professional conferences.[48, 49] The resulting awareness, peer review and comment were major contributors to the program's success.

The team addressed each of the FAA's Navigation and Landing Transition Strategy objectives for eLoran, along with the marine and timing aspects. The 2004 FAA report to DOT identified two principal objectives: 1) demonstrated performance in support of non-precision approaches, and 2) completion of work efforts to verify and improve integrity performance. By the time these aviation objectives were stated, the evaluation methodology had been changed from FAA Advisory Circular (A/C) 90-45[50] to Required Navigation Performance (RNP), which stipulates lateral accuracy. A Loran-based NAS system now must meet the more-stringent RNP 0.3 standard (+/- 0.3 nm "containment" at about 5.5-sigma or 1 event out of about 10-million), in order to qualify for support of instrument approach procedures.[51] (The A/C 90-45 requirement translates into an accuracy of about RNP 0.5, 2-sigma.)

Performance Requirement	Value
Accuracy (target)	307 meters
Monitor Limit (HPL) (target)	556 meters
Integrity	10^{-7}/hour
Time-to-Alert	10 seconds
Availability (minimum)	99.9%
Availability (target)	99.99%
Continuity (minimum)	99.9%
Continuity (target)	99.99%

The evaluation method is crucial to the qualification of a signal for a specified requirement, and the FAA's method involves five elements. From the 2004 Report:

Accuracy - Accuracy is the degree of conformance between the estimated, measured, or desired position or the velocity of a platform at a given time and its true position or velocity.

Loran system accuracy was improved by the installation of new transmitter timing equipment, the commitment to "time of transmission" (TOT) instead of system-area monitoring, receiver improvements, and improved propagation models.

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[48] See www.ion.org for proceedings and reprint availability. FAA/USCG team members have presented papers at ION meetings since the Congressional program began in 1997.

[49] See www.loran.org and contact the Operations Center for proceedings and reprint availability. Meetings of the International Loran Association since 1997 have emphasized presentations by the FAA/Coast Guard team members and progress toward defining and demonstrating eLoran.

[50] Federal Aviation Administration, "Advisory Circular 90-45A, Ch. 2," AFS-230, February 1975. See http://www.airweb.faa.gov

[51] "Loran-C Action Items from the March 19 Loran Murder Board," FAA Murder Board, March 19, 2002.

Integrity - Integrity is defined as the ability of a system to provide timely warnings to users when the system should not be used for navigation. In the eLoran case, as in GPS, Integrity is the “tall pole” in overall performance.

eLoran integrity was analyzed rigorously, using methodology developed for GPS. The eLoran receiver computes a Horizontal Protection Alert, the flag that annunciates position quality. An operation such as aviation instrument approach or harbor entry is flagged as unavailable if the horizontal protection requirement is not met for any reason. On the transmitter side, ”automatic blink” was deployed system-wide, and this function was included in the new timing equipment installed during the modernization program.

Availability - Availability is the ability of the system to provide the required function and performance at the initiation of the intended operation. Availability is also an indication of the system’s ability to provide usable service within the specified coverage area. Another related factor is system reliability, which is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions.

Unavailability due to p-static was removed as a problem through the demonstration of performance benefits using the magnetic-field (H-field) antenna. Transmitter replacements and design changes resulted in the higher reliability of solid-state units. TOT will remove the “chain” dependency of the Loran-C architecture which improves coverage by allowing “all in view” receiver operation and a host of other advantages.

GPS and eLoran are independent systems. A 99.9 eLoran availability supplements GPS availability of 99.999 and supports the nation’s navigation service at the RNP 0.3 level. In the absence of GPS, eLoran can continue to deliver the non-precision approach requirements for a backup.

Continuity - Continuity is the probability that the system will be available for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation. The factors that affect availability also affect continuity.

Continuity was improved through faster antenna switching between main and standby transmitters, plus upgrade of primary power and uninterruptible power systems.

Coverage - Coverage is the result of the preceding four factors. Coverage is the geographic area where the application-specific radionavigation system requirements (e.g., RNP 0.3 or HEA) for integrity, accuracy, availability, and continuity parameters are satisfied at the same time. System geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors that affect signal availability influence coverage.

See Figure 1 (which is Figure EO-2 from the FAA Report) for eLoran coverage meeting RNP 0.3. Members of the LORIPP consider the results “conservative” as described by the models used to extend measured performance to the entire CONUS:

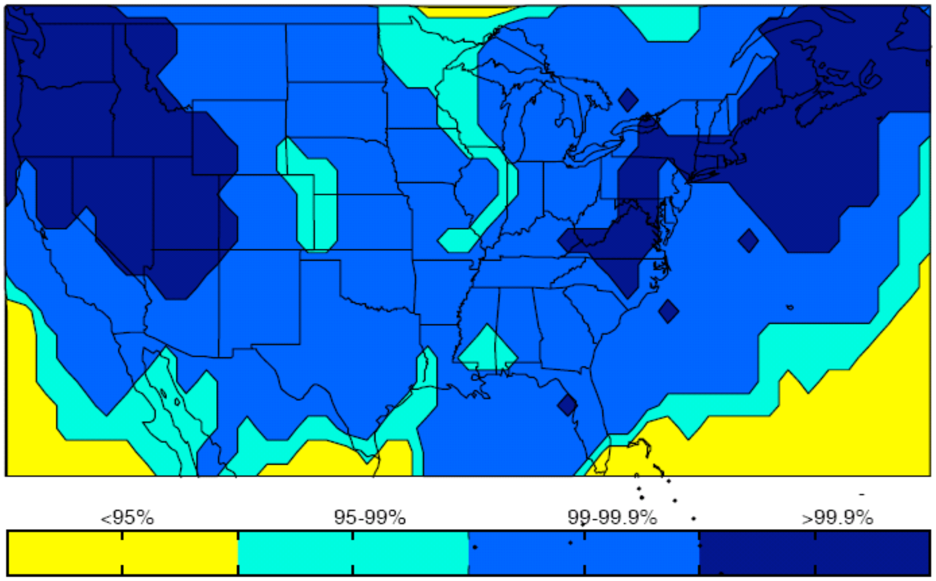

Figure EO-2. Expected RNP 0.3 Modernized Loran Coverage (Availability Contours in Percent) in the Conterminous United States with Existing Infrastructure (Which Includes the Canadians Stations)

Figure 1: eLoran Coverage, from the FAA 2004 Report

To demonstrate eLoran integrity in a manner, which can be compared directly with GPS, a "triangle diagram" that the team adapted from that originally developed at Stanford University for use with GPS and GPS/WAAS. An example appears in Figure 2.

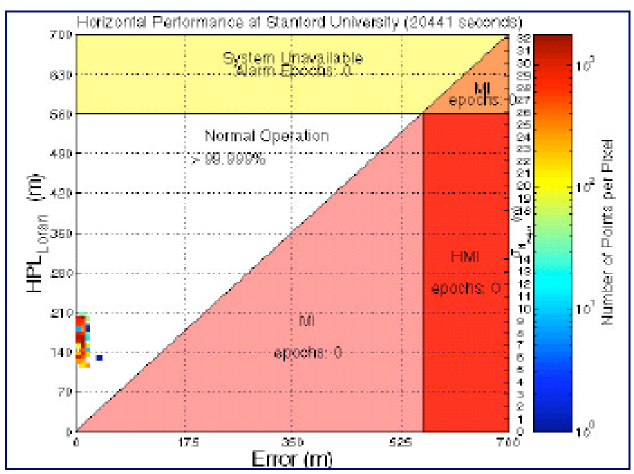

Figure 2: "Triangle Diagram" for eLoran, showing performance vs. alert thresholds

Loran Use Beyond Aviation

The FAA-managed Loran evaluation and modernization program recognized the potential for the Loran signal in space to serve the same wide audience being served by GPS. In addition to the FAA

RNP 0.3 requirements, Loran's ability to simultaneously perform the marine positioning and navigation and precision timing standards were evaluated.

Marine Performance

The marine requirements were stated in section 3.2.2 of the FAA 2004 report to DOT:

> *"Using the work of the International Maritime Organization (IMO) and the USCG's Harbor Entrance Approach studies, the evaluation team interpreted the requirements for harbor entrance approaches at the levels presented in Table 3.2-3 (reproduced below).*

Performance Requirements	Value
Accuracy (backup)	20 meters, 2 drms
Monitor/Alert Limit (backup)[24]	50 meters, 2 drms
Integrity (target)	3×10^{-5}/hour
Time-to-alert	10 seconds
Availability (minimum)	99.7%
Continuity (minimum)	99.85% over 3 hours

The marine accuracy requirement was demonstrated using differential eLoran techniques, drawing on past experimentation in this area, and from experience with the differential GPS systems used by the Coast Guard and FAA. Meeting this accuracy requirement was also shown to result in meeting the alert and integrity values. Coverage maps similar to the aviation requirements were presented for marine performance throughout the CONUS.

Timing and Frequency Performance

The timing and frequency users have no known published Government requirements that equipment must meet. Loran has a Stratum 1system that was required to hold within 100 nanoseconds of UTC. However, timing and frequency applications, including those used by government agencies, employ applications with specific timing and frequency requirements. The evaluation team used information from the DOT Task Force Report[52] to help define the time and frequency requirements, which are summarized in Table 3.2-4 (reproduced below) from the FAA Report.

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[52] DOT Radionavigation Systems Task Force, "Radionavigation Systems: A Capabilities Investment Strategy," January 2004 (Overlook Systems Technologies, Inc.).

Performance Requirement	Value
Frequency Accuracy (target)	1 x 10^{-13} averaged over 24 hours
Frequency Accuracy (desired)	1 x 10^{-12} averaged over 6 hours
Frequency Accuracy (minimum)	1 x 10^{-11} averaged over 1 hour
Antenna	No External Antenna (desired)
Legacy Use	Backward Compatibility (desired)
Integrity Data	Minimum "Use/No Use" flag
Timing Data	Time Tag, Leap Second Info
Timing Accuracy at the user's receiver	< 100 nsec (RMS)
Differential Data Update Rate	< once/hour

The team analyzed the timing and frequency needs of a wide variety of users, and concluded that the Stratum 1 requirements met by eLoran, serves most needs.

A recent cooperative government/industry study resulted in a paper[53] by Lombardi, Celano and Powers, which catalogs available timing signals. This paper acknowledges the importance of satellite-based timing services in the global time-transfer architecture. It also stresses the need for dissimilar signals of opportunity to ensure continuity of timing services during intentional or accidental interference with satellite systems.

The study concludes that "enhanced Loran" (eLoran – Loran-C augmented by timing and control-system improvements, and used in a GPS-like "all-in-view" mode) is potentially the best choice for U.S. GPS complement due to its advantages over the authors' second choice, WWVB. From the paper's conclusions:

> *"We have thoroughly reviewed all of the available broadcast signals that anchor the time and frequency infrastructure in the United States. As a result of this review, we have identified eLORAN as potentially the best available backup provider to GPS as a reference source for precise time synchronization and frequency control. With its large coverage area, its high level of redundancy due to multiple transmitters, and its ability to be received indoors, eLORAN also has the potential to become one of the leading providers of time-of-day information in the United States, a role that legacy LORAN-C was not able to fulfill."*

Since Loran systems exist in a large portion of the northern hemisphere, the conclusions apply outside the U.S. as well. See Figure 3.

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[53] M. Lombardi, NIST, T. Celano, Timing Solutions Corporation, E. Powers, USNO, "The Potential Role of Enhanced LORAN-C in the National Time and Frequency Infrastructure," presented at the 34th annual International Loran Association Convention and Technical Symposium, Santa Barbara, CA, October, 2006.

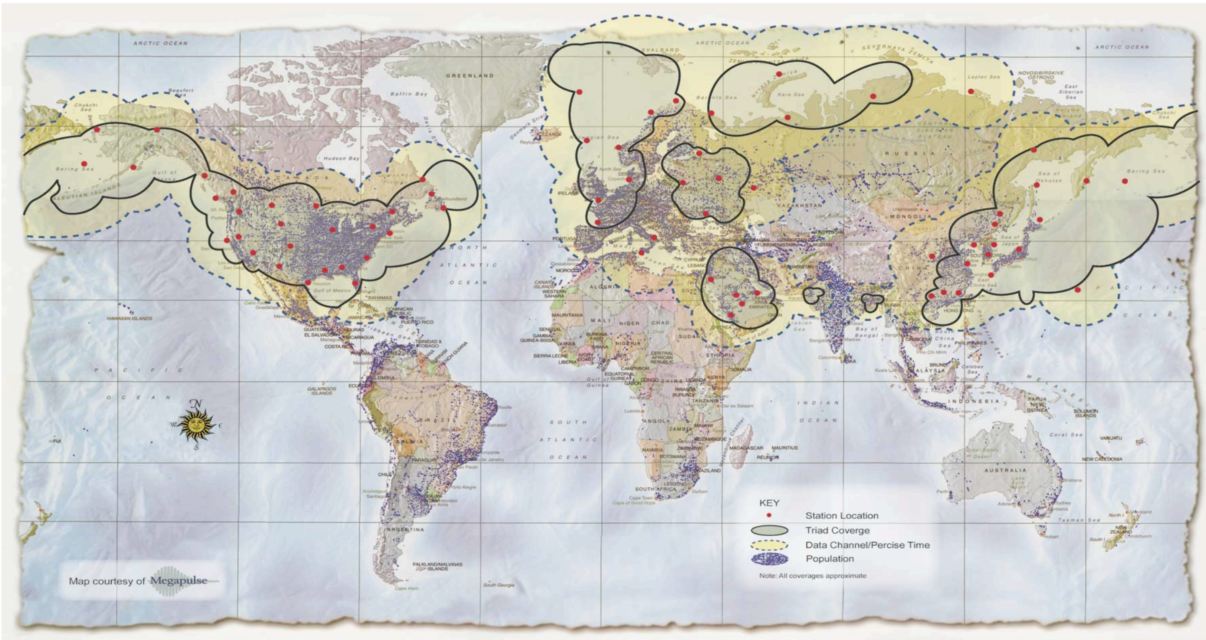


Figure 3: Loran-C transmitter locations and position/time coverage (courtesy of Megapulse, Inc.)

Land mobile and positioning requirements were addressed in the 2004 FAA Report, section 3.2.4:

> *"Numerous land applications (e.g., vehicle, asset, animal, and human monitoring or tracking applications) used Loran-C before the general availability of GPS. Loran is still viable for these applications, especially for critical or high-economic value applications where there would be a safety, security, or economic benefit in having a system available when a GPS outage occurred (e.g., tracking hazardous cargo). However, before these applications and Loran's use can be evaluated, the specific requirements must be identified and validated."*

A positive DOT decision to continue eLoran for safety of flight navigation will stimulate other operations and increase investment for protection and sustained PNT services. Additional applications using the integrated GPS/Loran PNT service will likely be created. One example has been demonstrated where contents inside a shipping container can be tracked.

Precision Timing for Aviation

While eLoran can provide precise time tied to UTC, what would be the value to aviation? There are three elements to this question; one is for use with ground systems where accurate timing is needed for networks, data fusion (time stamping of disparate sources of information) and communications. Most communications equipment requiring precise time relies on GPS (or the geostationary WAAS satellites) and then uses oscillators and/or atomic clocks for backup. Time stamping of surveillance targets from disparate radars, ADS-B receivers and other sensors could aid data fusion. The third element is the aircraft itself. Today there is no defined need for precise timing by itself from eLoran or any other source. However, precision timing is used within the GPS avionics to derive position.

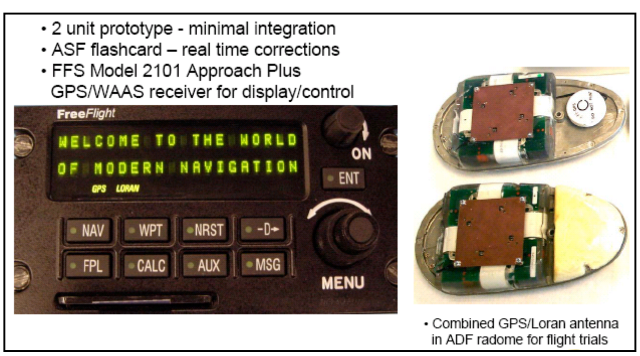
The future holds numerous possibilities, where precision timing becomes ubiquitous across communications, navigation, surveillance and networking. Keeping the aircraft connected as a node on the aviation network may depend on time synchronization in the future. Likewise, as demand for spectrum increases, on-board communications and bandwidth management may require time-division-multiple-access (TDMA) as a way of partitioning spectrum autonomously. In navigation and positioning, an aircraft with precise time can measure the arrival of signals from the ground (just like from GPS satellites, only looking down instead of skyward) and measure time of arrival. An application may be to use time-stamped transmissions from the ADS-B ground station and use the multilateration-derived position in the aircraft as the surveillance backup. While these "may" technology concepts are waiting for invention, two independent paths of getting timing to the cockpit (GPS and eLoran) are dependent on a favorable decision to continue support of Loran.

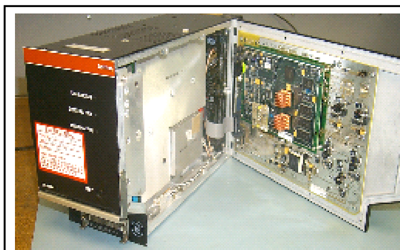
A greater national interest is that precision timing is critical to our economy in ways ranging from finance, timing the electrical grid, networking, etc. The disruption of time would have safety, security and economic impacts that would ripple back to directly impact transportation. The lack of timing backup in some industries that support aviation would seriously impact flight operations, the movement of people and goods by all modes of transportation, and would make a much better target than the use of GPS for navigation.

Market Risk

In the 2002 Navigation and Landing Transition Strategy the FAA identified Loran as high risk, principally because of the lack of avionics, either in the market place or on the aircraft. Due to the uncertain future of Loran continuation, even in the presence of $160 million of funding over 10 years of support from the Congress, the Loran market has dried up. But now with the breakthroughs in "all-in-view," interest in use has increased. There are commercially available combined GPS/WAAS/Loran systems available for the marine market and prototypes for aviation.

Avionics companies are working within the FAA-led Loran Program and are also using internal resources to evaluate functions and features of future integrated user equipment. Examples include the Rockwell integrated GPS/WAAS/eLoran receiver with multiple operating modes to study integration architectures. Free Flight Systems has prototypes operating in the evaluation program. Si-Tex is marketing a marine eLoran/WAAS receiver, and is finding buyers. OEM WAAS/eLoran devices are available, notably from Reelektonika (The Netherlands). Ryan International has worked on prototype antenna and receiver options.





GPS-Loran GNLU-930 Multi-Mode Receiver (MMR)

This industry interest base will materially help the process of finalizing standards and development of the certification path. During the FAA/USCG program, updated Minimum Operational Performance Specifications (MOPS) have been drafted[54] and are ready to support reactivation of the appropriate Radio Technical Commissions for Aeronautics and Marine Systems committees (RTCA and RTCM). These groups produce consensus documents that are the basis for provider-agency requirements for user equipment. In the case of eLoran, the path to certification of proponent equipment is well underway.

The "all-in-view" approach separates eLoran from its previous architecture by no longer needing chains of stations. This leads to some system cost savings over the long term. The technical transformation of eLoran makes it well suited to be a backup to GPS, significantly reducing the target value of GPS to intentional interference. Loran, due to its very low frequency and power, is very robust against jamming. eLoran can backup GPS and provide an additional on-board source for deriving position in support of ADS-B, a separate and independent means for meeting surveillance needs.

eLoran has met the requirements define in 2002 by the FAA Navigation and Landing Transition Strategy.

It has met the objectives reiterated in the 2004 FAA Report to DOT.

eLoran has demonstrated the capability to meet en route, terminal and RNP 0.3 non-precision approaches.

The system in CONUS is modernized and providing the necessary signals for PNT today.

The avionics market risk is no longer one of technology. Rather it is driven by three factors: 1) a policy for a backup to GPS without a stated technical solution for aviation, marine, land mobile, and timing, 2) indecision on the future fate of Loran signals, and 3) no request from the FAA to RTCA to begin standards development for an integrated GPS/WAAS/eLoran architecture. Each of these is a public policy decision. The future of eLoran is tied to recognizing that a backup to GPS is needed, it is economically viable to integrate eLoran as an element of avionics (as opposed to stand-alone receivers) for a combined GPS/WAAS/eLoran box, and that the timing to market is such that a capability is available as general aviation and air carriers upgrade from GPS to GPS/WAAS. Other modes of transportation and the timing community will add size to the overall integrated market, but only after the public policy decisions are made.

While DHS has required a backup as part of critical infrastructure protection, most industry segments like the power grid, telecommunications, IT, etc., are responsible for providing their own backup strategies (e.g., most cellular phone operators use GPS backed up with oscillators to provide up to 24 hours of backup capability), the Government is responsible for navigation for transportation. The Government must provide both the basic signal in space from GPS, its forms of augmentation (DGPS, WAAS) and now the backup signal source.

A backup system to GPS should provide the greatest similarity in operations as possible for the lowest cost to both the Government and the users. A backup need not be as robust as GPS and GPS/WAAS, but it must be able of accomplishing as many of the basic operational requirements as possible to safely recover aircraft and allow for continued operations.

[54] Two documents, which are the eLoran counterparts to RTCA DO-229C GPS MOPS and DO-228 GPS Antenna MOPS, have been drafted and are under review within the FAA.

The following section recognizes that eLoran is technically capable of acting as the backup, just like the 2002 FAA Navigation and Landing Transition Strategy identified DME, ILS and a subset of the present VOR system as an adequate positioning and navigation backup. The pro's and con's of each are discussed and then the cost of each of the options will be discussed.

Navaids Compared

The FAA has proposed that for air carrier aircraft, inertial navigation will be used as a backup, being updated as needed by DME-DME position fixes and be capable of providing either a non-precision approach to RNP 0.3 or as a means for establishing the aircraft on an ILS final approach segment to selected airports and runways. Important elements of this approach are 1) aircraft equipage with inertial navigation updated by scanning DME and 2) the proper geometry of DME ground stations to support RNP 0.3.

DME-DME Scanning Inertial

Pro's	Con's
Approximately 1,200-1,300 air carrier aircraft are capable out of approximately 4,700 aircraft.	A significant number of air carrier aircraft have neither INS nor GPS/WAAS.
Future aircraft are being bought with INS and scanning DME. While INS is a preferred RNAV backup to an RNAV capability available from GPS, aircraft incapable of using this backup strategy will continue well into 2025.	A typical existing inertial reference system has precession on the order of 2 nautical miles per hour (some are as good as 0.6 nautical miles per hour) requiring a position update during the missed approach to return and execute a second approach. Precession is not a problem for en route or terminal maneuvering but an RNP 0.3 approach is difficult to sustain without additional DME stations around airports.
In absence of GPS, DME can support INS and produce RNP 0.3 when the aircraft and multiple ground stations are within a 25 nautical mile range (see RTCA/DO-283A, Appendix C, Table C-2).	DME-DME ranging is dependent on not only the slant range, but the geometry of the DME ground stations relative to the aircraft (dilution of precision). Most general aviation aircraft do not use INS.
Most high-end business jets have inertial systems	While regional jets have equipped with GPS, few have inertial.
DME ground stations can be added near selected airports with the proper geometry to deal with dilution of precision.	While DME electronics are on the order of $50 K in cost, land acquisition, physical security and communications drive the cost for new locations higher. The cost of expanding the DME network to support scanning INS is an unknown that requires terminal area modeling. Siting of DMEs is very dependent on proper ground geometry to cover the approach path.
There are 972 DME systems maintained by the FAA.	FY 2004 operations costs for these DME was $25.5 million, just to cover a small segment of aviation and operations costs must grow to compensate for airport area coverage.

In Boeing's market overview, they see strong long-term growth in aircraft sales and fleet upgrades.[55] By 2025, about half of the fleet operating today will still be operating. The worldwide fleet size will nearly double and nearly 9,600 commercial air carrier aircraft will be replaced. The problem is that aircraft are being ordered today and airlines are committing to avionics configurations in absence of clear policy on backup for GPS. Likewise, the airlines are slow to equip with GPS and will likely not retrofit older aircraft that are destined to be replaced. Data on current fleet age and size for selected airlines shows that what is flying today will still be flying well into the future. Table 4 provides data from selected airlines.

Table 4. Airline Fleet Age and Number

Airline	Fleet Age	Number
AirTran	3.7	108
Alaska	10.0	110
Aloha	15.4	19
America West	11.9	108
American	13.3	699
American Eagle	5.3	267
ATA	6.6	25
Continental	8.5	356
Delta	13.1	434
Horizon	5.6	67
Jet Blue	2.8	97
Midwest	9.3	35
Northwest	10.8	266
Southwest	9.4	445
United	11.7	401
US Airways	10.4	248

Source: AirSafe.com, as of April 2006

If INS with scanning DME-DME is to be used as the standard for air carriers to continue to safely operate, to dispatch in the presence of interference, and to effectively lower the value of GPS as a target, then the FAA needs to 1) conduct the necessary surveys and coverage modeling to determine the cost of added DME locations to realize an RNP 0.3 capability, 2) define a retrofit strategy and certification roadmap, and 3) set a targeted date for carrying the INS backup.

If RNP 0.3 is not going to be used as the standard of performance, then INS with DME-DME is adequate, with the existing ground infrastructure, to support RNAV to an ILS final approach segment. While this will address an equipped segment of the air carrier fleet, there are still many aircraft that have no backup and may not even carry GPS at all. The lack of GPS is the direct result of the airlines holding off investment in anticipation that local area augmentation will be what they need to perform ILS-equivalent approaches. As the FAA defers local area augmentation, dependence on ground-based navaids will continue, further delaying any decommissioning.

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[55] Randy Vaseler, VP for Marketing, *Boeing Market Overview*, July 2006. Available at www.boeing.com

The FAA has proposed an incremental drawdown of the number of VORs. The operational concept is that aircraft (mainly general aviation) would be able to navigate VOR to VOR by proceeding direct. There would be no Jet Routes and Victor Airways. Additional VORs would be retained at airports to support non-precision approaches, although not all airports would be covered. An instrument flight rules floor would be established to assure line-of-sight reception of at least one VOR from anywhere in the CONUS airspace. Pilots could hop between VORs and get to an airport that either had a radial transition to an ILS or provided a VOR approach.

VOR-Based Backup

Pro's	Con's
VOR equipage is widespread so little or no user investment in needed in this strategy.	The retained subset of the network of VORs will need to be recapitalized to continue as a backup.
Additional VORs would be retained in mountainous terrain to accommodate general aviation where aircraft ceiling is a problem.	Pilots using RNAV as a routine would need to shift to an entire different operational mode in the presence of interference. While today most pilots are capable of operating in an RNAV and Victor Airway mixed environment, future general aviation pilots would only use VORs and fly VOR approaches in a rare instance of interference but would be expected to know the procedures and be tested on them.
The FAA can easily reduce its operating cost by a proportional share of current costs by reducing the network.	Based on FY 2004 results, the VOR is costing the FAA approximately $47.3 M per year to operate 1036 VORs and 105 VOTs and FAA would face modernization costs for those systems remaining.
The VOR can support non-precision approaches.	VOR is not able to support RNP 0.3, the suggested standard for the future NAS and the requirement set for eLoran.
VORs define today's airspace, not only in terms of Victor Airways and Jet Routes, but arrival and departure points for separating and sequencing traffic and with a VOR backup structure, many of these arrival and departure points could be retained.	Pilots are not able to take full advantage of RNAV today because the airspace is structured around VORs.
	While the number of VORs needed has been estimated and a minimum operating network is described in the 2002 strategy, no analysis on coverage and the impact of the minimum operating network on airspace structure has been completed. No safety analysis has been completed on the transition from RNAV to VOR-to-VOR direct in terms of pilot and controller workload.
	Removing some, but not all VORs will be more politically challenging as airports seek retention of their navaids.

While VOR is an appealing backup because of user equipage, modernization to a minimum operating network, which VOR locations to retain, a decommissioning waterfall for the others, and the necessary safety analyses should be completed so that overall cost of this option can be considered. The politics of decommissioning will be compounded by retention of some VORs. A total shutdown will be easier to manage. This is because of strong "not in my backyard" influences with the aviation community.

The FAA intends to retain ILS throughout the transition to satellite navigation. The approach recommended in the 2002 strategy was to retain all CAT II and III ILS systems and at least one existing CAT I ILS per airport to provide a backup for landing. In 2002, the prospect of both WAAS and a local augmentation (LAAS) being able to meet the performance of all categories of ILS was a significant driver in the strategy. Now that WAAS will deliver the same approach minima as a CAT I ILS, future ILS systems should not be added, some existing ILS units could be removed. All ILS systems at airports served by air carriers and some high activity general aviation airports serving as relievers in major metropolitan areas would be retained to continue providing approaches in the presence of interference and when the ceiling and visibility are below that of GPS/WAAS.

ILS as a Backup

Pro's	Con's
There is high user equipage with ILS.	Only useful as a backup for approach and landing.
Training for precision approaches is equivalent, whether it is ILS or RNAV/RNP with GPS.	ILSs will require modernization and service life extensions.
Congress continues to support funding for additional ILS locations.	Congressional earmarks are adding ILSs with marginal value and low use. Many of the existing ILSs on general aviation runways can be replaced with GPS/WAAS but decommissioning will be politically difficult.
The ILS final segment can be fed from RNAV sustained by DME-DME, VOR-DME, VOR, Loran, or radar vectors for sequencing.	WAAS equipage is just beginning within the general aviation fleet and few air carriers have the capability so removal of ILS in the short-term is not possible.
ILS is critical to reducing the value of GPS as a target for interference, since aircraft can continue to land.	Additional ILSs will be needed at large, delay constrained airports that add new runways in order to fully utilize the capacity.

A significant cost element for the FAA is the approach lighting systems that make up the total ILS package. The ILS units themselves are a small portion of the overall capital cost of an installed system. However, from an operation and maintenance standpoint, the localizer and glide slope cost nearly $73 million per year to maintain. Approach lights accounted for over $31 million in FY 2004. Reinventing approach lighting system design can reduce the approach lighting costs, but approach lights will be retained to support GPS.

In the 2002 strategy, Loran was considered an unlikely candidate; principally because of its uncertain future use for PNT across transportation and technical problems with being able to meet criteria for RNP 0.3 approaches. There is still considerable polarization on whether Loran should continue or not. As discussed earlier, the technical problems have been resolved, including manufacturers in the eLoran development has mitigated market risk, and now eLoran is a viable backup candidate awaiting public policy decisions.

ELoran as a Backup

Pro's	Con's
An RNAV backup for the RNAV GPS system.	No current avionics standard for an integrated solution.
The only complete PNT solution of any navigation aids currently in use except GPS.	No avionics equipage in the existing fleet for eLoran "all-in-view" technology.
Capable of producing RNP 0.3 approaches.	No clear policy regarding retention and operation of transmission sites.
Transmitters in CONUS have been modernized and producing a signal today. Alaska needs modernization.	Alaska modernization will cost approximately \$75 M to as high as \$140 M depending on the amount of USCG infrastructure and support added.
Transmitter and receiver technologies are known and have been demonstrated, making standards development easier.	DOT and DHS must reach an agreement on continuing or terminating Loran.
Congressional support for continuing modernization and adoption as a backup to GPS.	As a stand-alone avionics package, Loran would be unacceptable. Integration with GPS/WAAS is a viable way to develop the market and provide the backup capability.
Nearly Jamming proof because of the very low frequency and high power of transmission.	
"All-in-view" architecture delivers avionics capable of mimicking GPS performance.	
Future value of airborne access to precision timing and backup, while yet to be determined, can aid in supporting the aircraft as a node on a larger aviation network and open new opportunities in communications and surveillance.	
While not worldwide in coverage, Figure 3 demonstrates that the coverage is in those areas with high commercial aviation traffic and the most likely regions for interference of GPS.	

eLoran has been researched and tested as a stand-alone capability; however, the most logical transition to adding eLoran, at best value for the users and the Government, is as a backup to GPS is through development of RTCA minimum operational performance standards for an integrated GPS/WAAS/eLoran avionics architecture that is available in the 2009-2010 timeframe for addition to aircraft. This timing coincides with changes in GPS, the introduction of Galileo, and the significant growth in aircraft orders from Boeing and Airbus, the very light jet market, and continued improvements in general aviation avionics. By 2009, the PNT avionics suite standards must be stable and ready for the transition.

A positive decision to sustain Loran is backed up by the Volpe Center's benefit-cost report, available within Government as "Official Use Only" since 2004, which describes eLoran as inexpensive protection for the assets dependent upon PNT. While details of this report were not available to the authors, we have elected to use a range of cost values that best approximate Loran costs so as to then compare the cost of a Loran backup to the DME-DME and VOR strategies.

Backup Cost Considerations

There are two elements to cost; capitalization of assets or acquisition of new assets and the continuing operation and maintenance costs to sustain the services. Between now and 2025, the FAA will face modernization of VORs, elements of ILS systems, DME, and will also need to replace transmitters in Alaska for eLoran (three of which have already been procured). While the capitalization cost of eLoran has been estimated at $75 million for Alaska, the other capital costs are dependent on how many VORs would remain in the minimum operating network, and how many DME units and the associated land and communications would be needed. One estimate for the current ground-based navaid modernization was to be over $1 billion.[56] Operation and maintenance costs are available and can be compared across the choices for retaining navaids. Table 5 summarizes the results taken from the FAA FY 2004 operations budget allocation. An eLoran estimate is provided as a range, depending upon what cost elements the USCG includes. Approach lighting, visual aids to navigation, GPS and WAAS elements and runway visual range is not included in the numbers since they would be retained in supporting GPS approaches.

Navaid Category	Number in NAS	Total O&M
DME	972	$25,534,166
ILS (includes marker beacons, glide slope and localizer)	1134	$117,526,154
VOR (including VOT but not TACAN)	1141	$47,253,799
eLoran	28	$24 – 27 million

Source: FAA Operations Budget Allocation for FY 2004

DME, ILS and VOR combined represent $190 million of the annual $325 million cost of navigation. DME cost would grow because of the need to add additional locations near airports to meet RNP 0.3 and deal with dilution of precision caused by the geometry between the aircraft and the ground

[56] Russ Chew, *Rightsizing the FAA*, NAS Rightsizing Conference, Air Traffic Control Association, April 2005.

stations. DME is only a partial solution to a backup, requiring expensive inertial systems on the aircraft.

The USCG estimates an annual operating cost of $34 million that reflects additions to support assigned personnel. The operation and maintenance of Loran can be outsourced (OMB Circular A-76) and estimates range from $12 million to $15 million, provided that some of the Alaska modernization relocate some high cost locations since the need for a chain of stations is not as significant with the "all-in-view" architecture for receivers.

In the move to eLoran, changes to equipment and operating procedures are part of the process of meeting requirements for complementing GPS in support of critical infrastructure. Station staffing can be reduced to the minimum required for maintenance of availability. Remote monitoring and control may reduce the staffing requirement at many stations to zero.

A station off-air momentarily signals the onset of a period of signal abnormality detected at the transmitter. This method reduces the time-to-alarm in user equipment. Corrections to signal timing will be made more gradually than current step-wise corrections, aiding continuity of receiver lock.

Transmitter monitoring becomes highly automated, removing manual operations related to warning flags. "Automatic blink" monitoring is included in the new timing equipment at each transmitter.

eLoran system control changes to the Time of Transmission method, controlled by multiple Cesium clocks. Clocks are steered to UTC by two independent methods, one of which is completely independent of GPS timing. eLoran can be used with chain-independent architecture (all-in-view), enhancing availability and coverage.

The trade-off space for the DOT and DHS is between cost avoidance in capital expenditures and taking to lowest possible annual operation and maintenance cost for providing the backup service. The trade-space for the user is around adding something new or retaining the capabilities that presently exist. With so few air carrier aircraft equipped with scanning DME-DME inertial systems and a significant population of aircraft without GPS/WAAS, the time is right for decisive actions that can lead to integrating the backup strategy and the primary means of navigation together as one. What follows is a discussion of a transition strategy for the GPS backup.

Transition Strategy for Integrated Avionics

There are several assumptions that bring the timing of this strategy and its components together. It is a nexus of events that creates the opportunity to resolve the backup strategy, accelerate equipage, and begin decommissioning of surplus navigation aids.

- Significant new air carrier aircraft deliveries are expected starting in 2008 with the B787, B747-8, A380, and A350, as well as continuing strong orders for next generation B737 products. In the presence of clear policy, the backup can be added to the navigation suite.
- Garmin is currently offering an upgrade from GPS to GPS WAAS starting this year with over 70,000 installed units on general aviation aircraft. A backup decision can prepare the general aviation avionics manufacturers to create upgradeable interfaces to these GPS/WAAS avionics packages and begin work on GPS/WAAS/eLoran integration.

- Galileo is to become operational in 2012. This adds 30 more satellites to the constellation for navigation. It is important to note that the European Union is developing a radionavigation plan that considers eLoran as a candidate for backup and will likely follow the U.S lead on continuation of Loran.
- ADS-B will be introduced in 2009-2010 and the backup for surveillance need not be resolved early for en route, due to the existence of secondary surveillance, but in the Gulf of Mexico airspace, if separation is to be reduced to the equivalent of en route radar separation then an on-board ability to derive and report position is important.
- Sufficient RNP approaches are in place at the 100 top airports to shift toward an all RNP airspace, creating the opportunity to reduce selected VORs early and restructure the airspace to favor equipped aircraft.

The transition strategy starts with an action by the FAA Administrator asking RTCA to begin the GPS/WAAS/eLoran integration. This signals intent that the FAA plans on using Loran as an element of the backup strategy. It will take 12 to 18 months to produce the standards. There are test receivers that have been built and commercial marine versions integrating GPS/WAAS/eLoran exist. What the FAA is saying is that with the resolution of standards, an option is preserved to support an RNAV backup to GPS's RNAV capabilities. Interfaces to accommodate Galileo can be defined by the same RTCA special committee.

An industry day is held immediately following the decision to move forward with standards so as to up-level participants on the research and testing to get eLoran to the technical solution as a backup. Aviation equipage will be driven by the expected cost of the combined GPS/WAAS/eLoran avionics and whether or not the FAA also decides to decommission other navaids. A common misconception is that eLoran needs to be added as a stand-alone box.

The dialog between DHS and DOT on continuation or termination of Loran will likely continue well into 2007, even with a commitment from DOT to resolve the status of Loran by 2006. Assuming a decision to end Loran, the RTCA activities would stop, but assuming a positive decision to continue with eLoran, then standards will have been jumpstarted by at least a year. This leads to standards and production of avionics by 2009.

This nexus around 2009 to 2010 provides the opportunity to make the GPS/WAAS/eLoran box cost beneficial with a clear path to accelerated RNP operations, even for general aviation at a modest cost above the basic GPS/WAAS through the use of eLoran chip sets in the avionics. Once standards are approved, the FAA can define a schedule for an all RNAV National Airspace System, breaking dependence on Jet Routes and Victor Airways for aircraft separation. This change in airspace coincides with the deployment of the replacement automation for the en route environment. As equipage continues, benefits increase through efficiencies gained in use of the airspace.

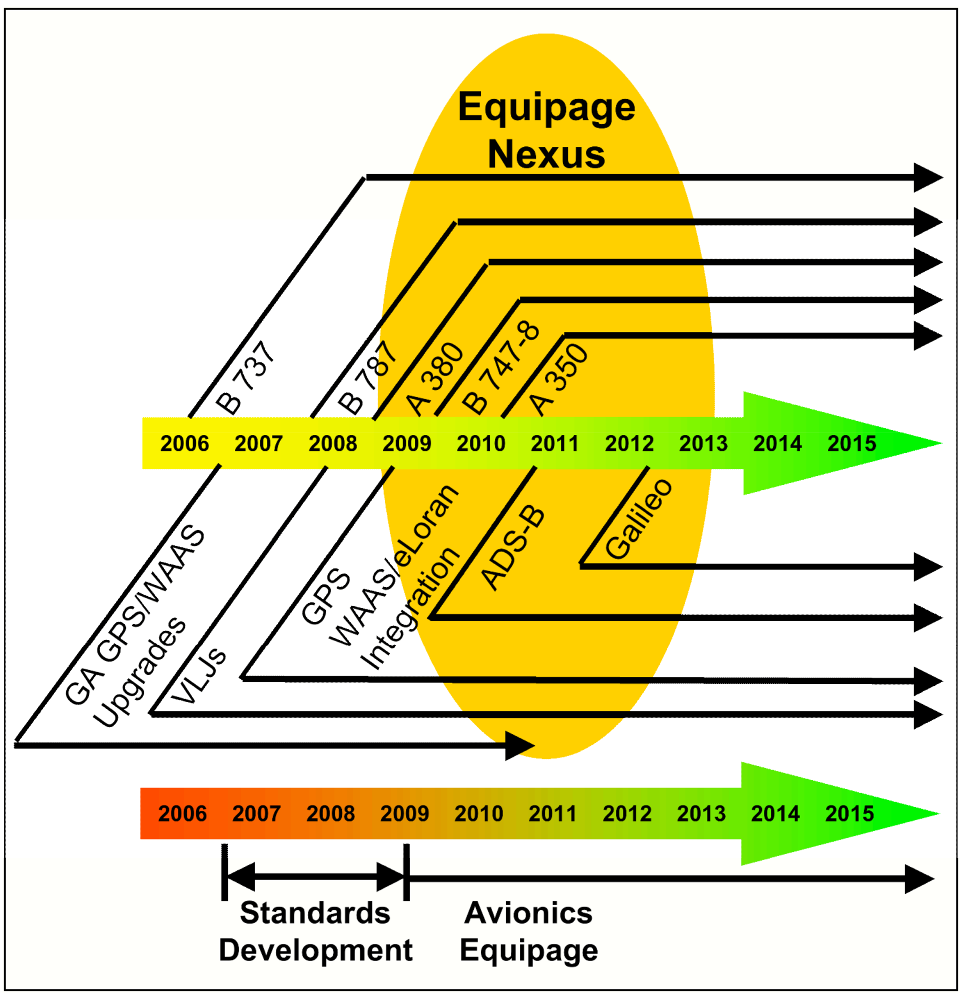
With an announcement from DOT on the continuation of eLoran, small demonstration grants can be issued on possible uses of precision time in aviation. This effort could be handled through the NGATS Institute. Why this technology search is important is that requirements have yet to be identified for timing in the next generation air transportation system. Work in FY 2008 and 2009 could be the basis for the DOT small business and innovative research program to stimulate potential timing opportunities and aviation innovation.

On ADS-B surveillance, eLoran penetrates buildings and jetways, so vehicles can equip with eLoran to derive position, improving ramp area coverage for command, control and security applications. The eLoran-derived position can serve as the ADS-B position report in the absence of GPS caused by interference. The use of eLoran with ADS-B provides an integrated, independent source for surveillance. This preserves the isolation of communications, navigation and surveillance to reduce common mode failures (all the C,N and S eggs in one basket).

In this proposed transition strategy for a backup, a key benefit to the FAA is a much clearer basis for removal of ground-based navigation aids with a targeted date to start that is tied to availability of the necessary avionics to begin the transition. The FAA can then modify airspace consistent with the transition to new automation in the en route environment. Between now and 2010, RNAV/RNP procedures are developed for airport arrival and departures, decisions can be made on adding eLoran transmitters in the Yucatan and the Caribbean for backup to ADS-B and its airspace redesigned around closing up the separation, and work can continue on completing the modernization of Loran in Alaska. Marine applications in the Gulf of Mexico would also be added by additional Loran coverage.

Figure 4 graphically depicts the avionics nexus, an opportunity to provide a cost-beneficial RNAV backup strategy to GPS's RNAV capabilities.

Figure 4. Equipage Nexus



Further delays in deciding the fate of Loran as a PNT backup to GPS will result in an opportunity being lost as GPS/WAAS avionics are sold without adding the eLoran functionality. Beyond about 2012, it will be too late to have sufficient value in the avionics to achieve equipage and FAA will be forced to recapitalize the existing ground-based navigation aids.

Conclusion

GPS and WAAS are national and international assets that provide services well beyond aviation and marine harbor entry. The DOD provides the GPS and the DOT provides the augmentations that are being widely accepted for all kinds of new services. GPS has stimulated the economy and businesses have grown up around the signal in space provided by the constellation of satellites. Every day, millions of our citizens directly touch GPS. Consider cell phones, E911, car navigation systems, flying in an airplane, recreational boating, banking and finance, or getting on a network to exchange information. Millions of other citizens are the beneficiaries of the efficiencies gained by cargo carriers and information carriers.

From a safety perspective, in the event of GPS interference, aircraft can be recovered and other flights prevented from flying. Ships entering harbors can drop anchor and wait off shore. E911 will not be as efficient, but the possibility of loss of life is small. But the economic consequence of halting segments of transportation due to the lack of PNT and impacting our nation's communications, power grid and other critical functions dependent on precise timing is measured in minutes, hours and days. Finding the source of intentional interference in minutes, hours or even days is unlikely, as evidenced from previous unintentional jamming events.

From a security standpoint, the best defense against an attack on GPS is to lower the target value by providing a sufficiently robust national backup that allows PNT to continue in a way that there is a significantly reduced safety risk and direct impact on our economy. Several hundred USCG personnel and $27 million a year are providing a future capability that protects the value of PNT, The issue of supporting a backup cannot be the funding. There are nearly 300,000,000 people in the United States – that is an insurance policy against PNT disruption that works out to less than 9¢ per year per citizen. In the context of the overall budget for homeland security, the federal responsibility to provide a backup is cost beneficial to both the citizens and those in Government that must provide navigation services.

The debate about continuing Loran cannot be around the willingness to use Loran. With over 10 years of uncertainty on continuing Government support of the signal, most former users have found other more expensive means of providing backup, especially the precise timing segments of our economy. With the right Government leadership and commitments, many of these segments will return to Loran, transportation users will benefit from the advances that make eLoran possible, and a true backup to GPS will become as ubiquitous as GPS itself.

If it is not the money and not the current user base, then the problem must be the staffing, the number of Coast Guard positions that are tied up in operating the 24 U.S. Loran stations. These women and men could be doing other higher priority work in our nation's homeland defense. The solution here is to either 1) divest the responsibility for Loran from the Coast Guard, or 2) outsource the operations and at the same time reduce the overall cost of providing the backup but retain responsibility within DHS.

For navigation, DHS would provide within their budget the national backup used by aviation and others, completing the last piece of an integrated solution to protect PNT as a national asset.
With the backup strategy for PNT, and the fact that the Government is providing the backup signal, the PNT policy should be modified to include a broader solution than just for aviation. The technology(ies) need to be named in the policy so that users can align their GPS configurations to include the backup.

Loran has changed from a “might do” in 2002 to a “can do” in 2006. It is the lowest cost national technology that provides full PNT backup for GPS, well beyond just transportation. A backup for PNT is a national imperative that goes well beyond aviation and marine navigation. As a national critical infrastructure protection need, the public policy required to implement protection for GPS and ultimately Galileo is a simple as a decision to continue Loran, complete the modernization, and get standards in place for eLoran.

Abbreviations and Acronyms

ABS	Automatic "blink" system (Loran transmitter monitor)
ADS-B	FAA Automatic Dependent Surveillance - Broadcast
AIS	Automatic Identification System (USCG)
AOPA	Aircraft Owners and Pilots Association
ATCA	Air Traffic Control Association
CERDEC	U.S. Army Communications and Electronics R&D Engineering Center
CNN	Cable News Network
CNS	Communications, Navigation and Surveillance
CONUS	Conterminous United States ("lower 48" plus the District of Columbia)
DGPS	Differential GPS
DHS	U.S. Department of Homeland Security
DME	Distance Measuring Equipment – aviation navigational aid
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOS	U.S. Department of State
DOT	U.S. Department of Transportation
E-911	Emergency location system operating in conjunction with cell phones
eLoran	Enhanced Loran-C, upgraded to meet aviation RNP 0.3 and marine HEA
FAA	Federal Aviation Administration
FBI	U.S. Federal Bureau of Investigation
FRP	Federal Radionavigation Plan
FY	Fiscal Year – U.S. Government October to September
GHz	radio frequency - gigaHertz
GLAs	General Lighthouse Authorities – UK and Ireland
GNSS	Global Navigation Satellite System(s)
GPS	NAVSTAR Global Positioning System
GPS-III	Upgrade underway to the GPS system to add frequencies, services.
H.R.	House Resolution (U.S. Congress)
HEA	Harbor Entrance and Approach (USCG)
IMC	Instrument Meteorological Conditions
IMO	International Maritime Organization (United Nations)
ILS	Instrument Landing System
INS	Inertial Navigation System
JPDO	Joint Planning and Development Office
KHz	radio frequency - kiloHertz
Loran	Long-Range Navigation system, operating at 100 KHz.
Loran-C	Legacy Loran system, approved for aviation enroute, terminal use
LORAPP	Loran Accuracy Performance Panel
LORIPP	Loran Integrity Performance Panel
MIT	Massachusetts Institute of Technology
MOPS	Minimum Operational Performance Specification (RTCA)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

Navaid	Navigational aid
NBF	National Boating Federation
NDB	Non-Directional Beacon navigational aid
NGATS	Next Generation Air Transportation System
NOTAM	Notice to Airmen
Omega	The former very-low-frequency (near 10KHz) global navigation system
PNT	Positioning, Navigation and Timing
P-static	Precipitation Static – in-motion charging and discharging of vehicle
RAIM	Receiver Autonomous Integrity Monitor
RCC	Range Commanders Council
RNAV	"Area Navigation" – geodetic waypoints and course guidance
RNP 0.3	Required Navigation Performance with +/- 0.3 nautical mile containment
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Marine Systems
SA	Selective Availability – until 2000, a limit on GPS non-military accuracy
SID	Standard Instrument Departure
SOHO	Solar and Heliospheric Observatory
STAR	Standard Terminal Arrival Route
TACAN	Tactical Air Navigation
TOT	Time of Transmission (Loran system control method)
TSO	Technical Standard Order (FAA)
U.S.	United States
UPS	Uninterruptible Power Supply
USCG	U.S. Coast Guard
UTC	Universal Time Coordinated
VMC	Visual Meteorological Conditions
VOR	VHF OmniRange - aviation navigational aid
WAAS	FAA Wide-Area Augmentation System – GPS accuracy and integrity
WWVB	NIST timing radio station broadcasting near Colorado Springs, Colorado
WWII	World War II
4-D	Four Dimensional (Lateral, Longitudinal, Altitude and Time)

Authors

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Dr. Lilley has a 30-year career as a University research director, industry chief scientist and vice-president, and as an FAA contractor. He has carried out analysis, investigation and flight evaluation of nearly every navigation system in the FAA's inventory.

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