

Benefit-Cost Assessment Refresh

The Use of *eLORAN* to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services

Final Report

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Executive Summary

In June 2004 the Volpe National Transportation Systems Center provided a “Benefit-Cost Assessment of The Use of LORAN To Mitigate GPS Vulnerability For Positioning, Navigation, And Timing Services,” to the U.S. Department of Transportation’s Undersecretary for Policy.

This report updates the Volpe Center’s 2004 assessment based on real-world events in the interim period coupled with the ever-growing world-wide dependence on GPS-provided positioning, navigation and timing (PNT) services for applications. PNT services in the U.S. include core national infrastructure such as provision of precise time and frequency, electric power distribution, and the transportation infrastructure (maritime, land surface, and aviation).

It is important to note that there are two kinds of data used in this analysis: costs and benefits. As in 2004, the Volpe Center approach has been to get costs as accurately as possible, and sample the benefits. Thus, the study provides a conservative, lower limit to the benefit-cost ratio, which is the ratio of estimated benefits incurred to GPS users in the U.S. over the costs incurred in providing a backup to the GPS services.

The conservative lower limit to the B-C ratio used in this report means that the true ratio can only be higher. While it is beyond the scope of this refresh to provide details, costs of a GPS outage for the telecommunications, timing and electric power infrastructure will be significant. The disruption of the electric power grid due to a loss of GPS timing, for example, might be in the range of 20 to 30 times the effects estimated here for transport-related consequences¹.

The Volpe Center also recognizes that user equipment costs certainly should be addressed in a study integrating GPS and the enhanced Long Range Navigation system (eLORAN). For the purposes of this analysis, chip sets integrating GPS and eLORAN capability are assumed to be part of the GPS equipment, with eLORAN representing a minor share of this cost. The cost of the additional LORAN antenna has been added.

Although this report only addresses civil applications of GPS and eLORAN, it is understood that military uses of GPS may also benefit from the availability of eLORAN provided PNT services.

¹ Although the August 2003 blackout that originated in Ohio was not caused by a GPS disruption, the large economic impact of this event is worth noting, because of power industry plans for ever more precise grid synchronization and grid fault detection and remediation, to be achieved using GPS, as noted in the “PNT Services” section of this report. (See also “The Economic Impacts of the August 2003 Blackout,” Electricity Consumers Resource Council, February 9, 2003, at <http://www.elcon.org/Documents/EconomicImpactsOfAugust2003Blackout.pdf>)

eLORAN remains a viable, cost-effective potential back up for GPS. It is currently the only non-satellite Positioning, Navigation, and Timing (PNT) system that has been tested and can provide a multi-modal back up for the PNT services GPS provides. Given the growing importance of and dependence on PNT services, it is increasingly cost-beneficial to provide back up capability to those services. The commercial applications dependent on GPS PNT services have grown into markets that were previously unforeseen. There is little doubt that this trend will continue.

In summary, the analysis presented in the body of this report leads to the following conclusions:

- The benefits of eLORAN would exceed the costs if, over the course of the 15 year study period, eLORAN backs up a single GPS outage of significant size. Positing a large but plausible outage scenario yields a Benefit Cost Ratio of 5.6 for a single backing up.
- The LORAN infrastructure has already been significantly upgraded to achieve eLORAN capability as a result of ten years of Congressional support and \$160M of funding. It is already operating and the newer, state-of-the-art components remain, so it is available for the cost of completion of the modernization.
- Backing up GPS would maintain efficiencies in the US logistics system that benefit our economy through improved logistics and communications, including safety of life and security applications, such as Maritime Domain Awareness.
- Many wireless phone customers in the U.S. depend on GPS as the source for time and frequency needed to operate the networks. These systems will cease operation with loss of GPS signals, and the increased load on other networks will degrade service.
- Perhaps the greatest benefit of all remains that a robust back-up to GPS-provided PNT services makes GPS a less desirable target, and reduces the risk that it would be attacked at all.

Introduction

The June 2004 Volpe Center report, “Benefit-Cost Assessment of The Use Of LORAN To Mitigate GPS Vulnerability For Positioning, Navigation, And Timing Services,” was a response to a limited question:

“Given the need to provide a GPS backup, is an enhanced LORAN² more cost-beneficial than not having enhanced LORAN?”³

Purpose of this Report

This report is an update⁴ to the results of the June 2004 report. However, based on the real-world events during the interval between that report’s release and the preparation of this one, the premise of the earlier report, “if a GPS outage occurred” is replaced by “when a GPS outage occurs.” This change in perspective, coupled with an ever-growing dependence on GPS for more and more civil applications⁵, reinforces the need to re-visit the original question.

Increased Reliance on GPS

Over the last five years, the list of applications depending on positioning, navigation and timing (PNT) information (i.e., those applications that use GPS) has grown beyond the most optimistic predictions. New applications were expected, of course, and unanticipated applications are in fact part of the innovation process⁶. In U.S. civil aviation, the most important development is the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) program that seeks to modernize the U.S. National Airspace System (NAS) in a transformational way, and which relies heavily on GPS for navigation, surveillance and communications applications. In the marine domain, GPS equipment is widespread and is mandatory for large vessels. The Federal Railroad Administration is also utilizing GPS in its Positive Train Control system.

Largely unforeseen, however, was the creation of an entire industry providing “mobility apps,” which utilize GPS and leverage the growth in the number and

² LORAN is an abbreviation for “LOng RAnge Navigation”; GPS is an abbreviation for “Global Positioning System.”

³ “Benefit-Cost Assessment Of The Use Of LORAN To Mitigate GPS Vulnerability For Positioning, Navigation, And Timing Services,” Volpe National Transportation Systems Center, June 8 2004.

⁴ The resources available for preparation of this report were consistent with an incremental update to the previous report, rather than a full repetition of the earlier effort. Consequently, a full understanding of this report may require a review of the earlier document.

⁵ This report addresses civil applications of GPS and LORAN. However, it is understood that military uses of GPS may also benefit from the availability of LORAN.

⁶ See, for example, the discussion in “Uncertainty and Technological Change,” by Nathan Rosenberg, pp. 91-110, in *Technology and Growth*, Conference Proceedings, Federal Reserve Bank of Boston, June 1996.

capabilities of wireless phones and other handheld devices. The acronym LBS, for location-based services based on these devices, was recently coined to describe this market. This has helped reinforce the perspective that GPS is an enabling technology, with PNT being described as more of a “superstructure” than a separate infrastructure for the economy.

In addition, the often critical need for precise time and frequency cannot be emphasized enough. This need applies not only to the transportation sector, but also to networks, telecommunications and electric power (see Appendix B, which contains background material on timing, and on some aspects of aviation and maritime operations). The increase in application and continued dependence on GPS and the various services it enables brings with it the potential for concomitant losses, should the GPS service become unavailable. The 2004 benefit-cost analysis described potential scenarios for GPS outages and their consequences. These scenarios and additional scenarios of actual events are examined in this update to determine if the benefits of using enhanced LORAN (eLORAN) to mitigate the impact of the GPS outages are, as before, valid and significant. In doing the analysis both planned and unplanned outages are described, with unplanned or intentional outages leading to the largest consequences, and hence the largest benefits if these are mitigated by the back-up system⁷.

Methodology

This benefit-cost analysis (BCA) refresh of the 2004 analysis applied Office of Management and Budget (OMB) standards coupled with conservative assumptions on benefits accruing to GPS users who could also use eLORAN. The conservatism means in part that many quantifiable benefits were not included, and, although they were described, their values were not added to the quantified benefits.

Report Overview

This summary report consists of three sections:

- Executive Summary;
- Report body, in seven chapters;
- Four appendices

The chapters of the report body are:

- Introduction (this one) states the purpose and context of the report;
- Background provides summary information of about role of Positioning, Navigation and Timing (PNT) services in 2009 and the status of LORAN;

⁷ Throughout this report, outage refers to the making GPS unusable due to jamming (spectrum denial), spoofing (making a satellite appear to be in a position or time it is not), or having an insufficient number of satellites for the application.

- Quantifiable Benefits describes the benefits of a GPS backup system which are either quantified herein or are potentially quantifiable but not due to lack of reliable information or complexity;
- Unquantifiable Benefits describes “soft” benefits (e.g., world leadership) which, while real, likely can never be quantified;
- Baseline and Alternative LORAN Configurations describes and provides cost figures for the four possible future LORAN infrastructure configurations considered herein;
- GPS Outage Scenarios describes four possible scenarios whereby GPS PNT services are lost, and provides figures for the benefits (costs avoided) accrued by having a backup system; and
- Summary, Conclusions and Recommendations synthesizes the main points of this report.

The appendices to the report body are:

- Appendix A: Assumptions and Alternatives is a concise (bulletined) listing of the assumptions used in the analysis;
- Appendix B: Timing, Aviation Operations and Maritime Domain Awareness contains comments received from other Federal agencies on the body of this report;
- Appendix C: Detailed Costs for Baseline and Alternatives is a one-page table of LORAN costs broken down by year and configuration alternative; and
- Appendix D: Detailed (Undiscounted) Benefits by Scenario and Sector is a one-page table that shows the costs avoided by having a LORAN backup, broken down by year, outage scenario and applications sector.

Background

LORAN

LORAN has a better than half-century history as a successful navigation system, principally through its longest running incarnation, LORAN-C. LORAN-C, still operating, has provided mariners with positioning, navigation and timing services prior to GPS⁸. As GPS became more capable (e.g., completing the constellation and updating satellites), and finally ubiquitous, LORAN use waned. The events of 9/11 and the information presented in the Volpe GPS Vulnerability study⁹ underscored a need to examine GPS applications and their vulnerabilities. This helped to develop support for the modernization of the LORAN system that will ultimately lead to an enhanced system, eLORAN. Today, LORAN-C has been significantly upgraded to what is called “modernized” LORAN¹⁰.

LORAN-C has been perceived by some to be an outmoded technology superseded by GPS. In truth, eLORAN in its updated form can provide many PNT services on par with GPS. More significantly, eLORAN makes GPS a more reliable system by mitigating many of its vulnerabilities. eLORAN is currently the only non-satellite PNT system developed and tested that can provide effective back up for most of the PNT services GPS provides. The technical capabilities of eLORAN have been described in reports such as the FAA-sponsored research on LORAN enhancement¹¹ and the National Institute of Standards and Technology¹².

PNT Services

The value provided by positioning and navigation services is understood intuitively by anyone who has ever needed directions. These services underpin the functioning of modern economies, and their use is integral to all critical infrastructures. Precise timing and frequency services are likewise ubiquitous throughout the economy, and are necessary to the functioning of critical networks, for example, as well as the transportation and electric power distribution sectors. GPS provides reliable PNT

⁸ LORAN continues to provide a means of PNT services for multimodal and multipurpose PNT applications e.g., coastal navigation, enroute flight and communications timing.

⁹ “Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System”, Volpe National Transportation Systems Center, August 29, 2001.

¹⁰ “Modernized” is the preferred term. The modernization includes a change from vacuum tube technology transmitters, to the more robust solid state technology, with its lower operational costs. In addition, recent enhancements put modernized LORAN on the threshold of providing PNT services that can adequately perform the GPS backup function in many key civil applications.

¹¹ “Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications,” prepared for the Federal Aviation Administration, Vice President for Technical Operations, Navigation Services Directorate, March 2004.

¹² Lombardi, M., C. Norman, and W. Walsh, “The Role of LORAN Timing in Telecommunications,” presented at the Radio Technical Commission for Maritime Services (RTCM) annual meeting, May 2006.

services at no added cost to virtually all citizens who use the infrastructure of a modern society¹³.

In the five years since the 2004 BCA report was completed, the national aviation infrastructure renewal program, Next Generation Air Transportation System¹⁴ (NextGen), has transitioned from early planning status to a combination of early implementation of some projects and detailed planning of others. The NextGen program's intent is a "transformation that will change the face of aviation"¹⁵. It will rely heavily on GPS to achieve this goal, including the following projects:

- Automatic Dependent Surveillance – Broadcast (ADS-B) — Aircraft broadcast of their position coordinates to Air Traffic Control (ATC) facilities and other aircraft, enabling new operations to be defined and implemented.
- Required Navigation Performance (RNP) / Area Navigation (RNAV) — Enables new airways and approach/departure routes to be defined.
- Local Area Augmentation System (LAAS) / Ground-Based Augmentation System (GBAS) — A single LAAS/GBAS installation at a major airport is planned to provide Category II or III precision approach and landing capabilities¹⁶ at all runway ends.
- Wide Area Augmentation System (WAAS) Localizer Performance with Vertical guidance (LPV) — WAAS LPV provides near-Category I approach and landing capability at every runway end in the Continental United States (CONUS).

The net effect of these projects will be a significant increase in the capacity of the National Airspace System (NAS) and corresponding reduction in delays. eLORAN can maintain effective synchronization for the WAAS ground network; it also can be developed to provide most surveillance and navigation requirements for general aviation and regional aircraft in en route, terminal area, and non-precision flight phases. DME and radar infrastructure will be retained as necessary to provide backup capability in the event of loss of GPS.

PNT timing services affect applications that require accurate knowledge of precise time and time interval (PTTI).¹⁷ These services range from the "clocks" in the Internet managing the data packets to controlling the electric utility system. It has often been noted that the successes of the services provided by GPS are such that operators of the systems depending on this information are unaware of how the information from multiple sources is blended. From a user perspective, they really don't need to know - it just works. From a critical infrastructure support perspective, however, it is important that

¹³ "Mitigation of GPS Brownouts," testimony provided by Dr. Brad Parkinson, Stanford U., May 5, 2009.

¹⁴ When the earlier report was published, the NextGen program was called Next Generation Air Transportation System (NGATS).

¹⁵ *NextGen Implementation Plan 2009*, Federal Aviation Administration (FAA).

¹⁶ Higher category numbers correspond to operating at lower cloud ceilings and/or horizontal visibilities.

¹⁷ "Time interval" relates to frequency, an important parameter connected with clock and network synchronization. Thus, GPS, LORAN and atomic clocks, among other devices, provide precise time and time interval (PTTI) services.

adequate knowledge of service delivery methodology, reliability, maintainability, continuity of service, integrity of information, etc., be thoroughly vetted and well understood. This report and the previous version consider some of the consequences of the PNT source failing to work, and describe the benefits of maintaining PNT services.

Electric power distribution is managed by making synchronized measurements at high frequency across wide areas of the power grid. A good, widely available PTTI source is required to synchronize the measurements to high precision. In addition, modern communications also depends on precisely segmenting and sharing frequencies and time availability, to increase the number of users and the quality of service. This multiplexing capability is quickly lost when the time signals upon which everything is synchronized are lost. Hence, it can be difficult to communicate using networks lacking sufficiently accurate clocks and modern, secure equipment.^{18,19}

Mitigating the Loss of the GPS Signal

The necessity of providing a means to mitigate the impact of a loss of GPS is not in doubt. LORAN (or eLORAN) can provide most of the required PNT services, and provide them in a manner that is also complementary to GPS. The latter feature increases eLORAN's attractiveness as a GPS back up.²⁰

As a candidate backup to GPS, LORAN need not and does not provide all of the capabilities of GPS. In particular, LORAN does not provide vertical position/altitude information, and thus cannot be used for aircraft precision approach. However, LORAN does have very wide coverage and provides both accurate horizontal position information and (uniquely among candidate GPS backup systems) accurate PTTI information.

The financial case considered in this benefit-cost analysis is limited to the economic impact of the loss of GPS availability absent mitigation. Since LORAN has a long history, this simplifies some of the tasks associated with cost estimation. eLORAN builds incrementally on known capabilities. It involves adding capabilities that have been tested, thus reducing greatly the related technical uncertainties and resulting costs that are part of a benefit-cost analysis. The major *cost* uncertainties involve decommissioning costs related to site remediation.²¹ Other cost assumptions relate to the

¹⁸ See, for example, the descriptions of the importance of timing and time interval services in, "Global Positioning System Timing Criticality Assessment – Preliminary Performance Results," Carroll, J. and Montgomery, K., presented at the 40th Annual Precise Time and Time Interval (PTTI) Meeting, 2008.

¹⁹ See also "GPS Jamming and the Impact on Maritime Navigation," Grant, A., et al, *The Journal of Navigation*, Vol. 62, No. 2, April 2009, pp. 173-187.

²⁰ LORAN is a terrestrial system, while GPS is space-based. LORAN provides a long wave, high power signal, while the GPS signal has low power and a short wavelength. Thus, GPS requires a direct line-of-sight between the satellites and the user antenna, while LORAN offers better penetration into tree canopies, urban canyons, and building interiors. The shorter wavelength GPS has relative to LORAN, however, is the basis for the greater accuracy provided by GPS.

²¹ Mothballing has been suggested as a stop-gap alternative. However, the speed with which existing facilities age both functionally (as technology advances) and physically (many current stations are remote and exposed to extreme weather conditions) make stasis an unrealistic option. In addition, user equipment would not likely be available. It is doubtful industry would embark on development of user equipment for

various alternatives. For example, assumptions which involve the relocation of two Alaskan LORAN stations, the amount of and schedule for improvements, and resulting cost avoidance are described.

The principal *benefits* accruing to eLORAN derive from its ability to continue the provision of PNT services to GPS users during a loss of the GPS signal. These services are used to protect and manage critical infrastructure. PNT services include every facet of the modern economy. The loss of efficiency gains in marine shipping and logistics management, for example, account for the majority of the savings attributed to positioning and navigation. The communications services include time-stamped automatic financial transactions and direct communication of voice and data over the radio spectrum or the Internet, the latter enabling the growth in LBS. Aviation has also become a major consumer of GPS services. Quantified benefits under consideration also include cost avoidance due to investments in technology, as well as savings from shutting down LORAN entirely.

Perhaps the greatest unquantifiable benefit of the existence of a back up is that a practical, seamless, near-transparent back up for GPS reduces the risk of GPS being purposely attacked. This is a desirable quality in a PNT back-up service, since it offers a broad resilience to many GPS-related threats. Whether satellites are removed from the GPS constellation due to a hostile act or an inadvertent equipment failure jams a signal, necessary PNT services would remain intact.

LORAN User Equipment

Because of the uncertain nature of the Government's commitment to continue LORAN operation, the benefit-cost ratios presented herein must be considered as potentially achievable rather than available immediately. For the most demanding transportation mode, commercial aviation, it is unlikely that user equipment could be placed in revenue service in less than five years — two or three years for RTCA, Inc. (formerly Radio Technical Commission for Aeronautics) to develop performance standards, and another two to three years for the FAA to issue Technical Standard Orders (TSOs), equipment to be designed, manufactured, certified and installed on aircraft.

“mothballed” equipment. Lastly, the salvage value of such a “time capsule” approach is likely to be very small.

Differences Between This Report and the Prior Version

Scope

As part of refreshing the earlier analysis, the alternative LORAN configurations and their costs were revisited, assumptions were checked and adjusted where required, and associated data elements were updated as needed. The outage scenarios used in the earlier report remain intact. One update involving the scenarios was to ensure they reflect realistic examples of the results of jamming trials and actual events concerning the latency of the precise time. A primary interest for this update was to provide a wider discussion of the potential benefits and their sources than was previously attempted.

As in the 2004 CBA report, a thorough evaluation of all sources of benefit from GPS is outside the scope and resources of this report. However, as GPS usage becomes more common, it is worthwhile to describe, even qualitatively, the significant areas in which dependence upon GPS gives rise to benefits from using a back up.

Price Level and Discounting

The change in price levels and dollar values was made to ensure that prices are expressed in current dollar (2009) terms. Similarly, the discount rate, previously set by OMB at 3 percent, is now 2.75 percent. A smaller discount rate means that future benefits and costs are valued more in the present.

Cost of Fuel

The cost of oil is a principal component of operating costs for transportation. In 2004 the price of oil was around \$35 per barrel (or in today's dollars, about \$39), but recently experienced historic volatility as it rapidly approached \$140. It then experienced an even faster decline, and currently moves between \$70 and \$80 per barrel at the world price. The cost per barrel continues to be volatile, and has recently been below \$40 in the U.S., essentially back to 2004 price levels, a result of the current economic downturn. Since oil is such a significant contributor to the operating costs of all modes of transportation, and savings in such costs are a key component of the benefits of GPS, the price of oil affects the future benefits imputed to eLORAN.²²

²² See www.oil-price.net for updates. Other sources include the Department of Energy's Energy Information Administration, at www.eia.doe.gov/, which forecasts out to 2030. Also, a recent study of the benefits of GPS for personal trips and the resulting gasoline savings, which were valued at \$192 per driver per year, was conducted. See http://reviews.cnet.com/8301-13746_7-10229438-48.html for the text of the article describing the report.

Quantifiable Benefits

The principal benefits accruing to eLORAN operation derive from its ability to provide PNT services to most GPS users during a loss of the GPS signal. The PNT services are used to protect and manage critical U.S. infrastructure. In many applications, GPS is a single point of failure. PNT services involve every facet of the modern economy. They reach across all modes of transportation, and significantly impact timing services in other key areas such as communications and electric power distribution.

Many, but not all, GPS benefits can be quantified in dollar terms. The benefits that are most easily quantified are not necessarily those that are the largest or most significant. Likewise, those that cannot be easily quantified are not necessarily unimportant. Benefits from efficiency to maritime logistics have been studied and are currently being reaped. Likewise the value of cell phone communications can be estimated by what people pay for voice and data transmission. The value of just-in-time delivery, aided by GPS, is harder to derive, but the benefits are no doubt significant in dollar terms.

The value of communications to first responders is also significant and, because it is situationally dependent, this value is even more challenging to quantify, since assumptions about future user equipage add another dimension to the uncertainty of a forecast. The issue of user equipage is probably most keenly observed in trying to understand the potential benefits of a GPS backup for aviation. This will depend upon operational efficiencies that have not yet been realized, at rates of adoption that are unknown. Therefore, these types of benefits of a backup to GPS are termed quantifiable, although actually quantifying them would require vetting too many assumptions to be practical in the current report.

The improved robustness an effective PNT back up brings to GPS is a desirable quality since it offers a broad resilience to many GPS-related vulnerabilities, some of which appear to be increasing²³.

Maritime Benefits and World Trade

Estimates in the earlier report were based upon the levels of maritime trade and the maintenance of the benefits gained from efficient transit with GPS. Trade continued at a robust rate of increase until the recent recession, which resulted in port activity being reduced by roughly one-third. Again, the valuation of benefits of a back up hinge upon the continuation of services at forecast levels of the activities being supported. Thus, while forecasts of global trade are currently based on a rebound of the world economy, it is important to point out that the forecast errors surrounding these are, generally, not known. These uncertainties are likely asymmetric, however, with a greater potential for

²³ GAO report GAO-09-325, "Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities", May 2009.

an increase in oil prices and trade, rather than further decreases. Higher oil prices increase logistics costs; hence the benefit of maintaining efficiencies increases.

In the face of these uncertainties, the analysis of the maritime sector is left intact from the 2004 BCA, and the update is limited to reflect current price levels.

It is worthwhile here to emphasize the mechanisms through which additional maritime benefits accrue, in addition to those related to flow of maritime commerce. These include many GPS-dependent systems, which themselves contribute to safe, secure, effective and efficient maritime commerce, in addition to enabling efficient routing, tracking, scheduling, etc., by providing situational awareness, safety and security. Some of these GPS-dependent²⁴ systems are:

- Automatic Identification System (AIS)
- Long Range Identification and Tracking (LRIT)
- Maritime Safety and Security Information System (MSSIS)
- Search and Rescue Satellite Aided Tracking (SARSAT)
- Ship Security Alert System (SSAS)
- Global Maritime Distress & Safety System (GMDSS)

These systems are critical to specific activities such as search and rescue operations. They also have more general application, such as enabling Maritime Domain Awareness (MDA), and some are interdependent. All of these applications, however, depend on GPS, and they are key components of MDA and national security. While it is beyond the scope of this refresh of the 2004 BCA to determine the benefits of MDA, it is still an unquantified component of the benefit of GPS, and hence of using a GPS back up.

Telecommunications Benefits

The earlier Volpe Center BCA report used extant trends in telecommunications to forecast the value of those services, hence the benefit to preventing their disruption. The industry grew approximately fifty percent faster than was assumed in the 2004 analysis, and spawned new products and services which coalesced into the location-based services industry.²⁵ A conservative approach to benefits estimation was used, with market penetration of cell phones capped at 80 percent. The actual rate of market penetration for 2008 was 89 percent²⁶, according to a Harris poll. Likewise, the estimated U.S. population at that time was almost 295 million, whereas the actual population reached over 306 million. The result of updating these figures is a ten percent increase in the current user base, and the opening of revenue streams from new services.

²⁴ In many of these systems GPS is a single point of failure node.

²⁵ The average rate of growth posited for telecom was about 9.5 percent through the study period, and the actual rate of growth for 2005 was 14 percent.

²⁶ See http://www.harrisinteractive.com/harris_poll/index.asp?pid=890.

Industry expectations are for growth in voice communications at about the rate of inflation, with data traffic expected to increase by 14 percent annually over the next eight years. These contribute to significant increases in the estimated benefits over the study period, with a faster growing user base growing revenues faster than had been previously assumed.

The above benefits are quantified using average monthly billing rates applied to estimates of users and penetration rates for service. The benefits of maintaining service provision during a loss of GPS time and frequency will also include the mitigation of spill-over effects onto other networks. This is much more difficult to quantify, as it relates to the likely degradation of communications services, as opposed to their denial, and, while likely significant, is not included in this analysis.

Benefits that are conceptually quantifiable but have not been quantified for this analysis are described next.

Aviation Benefits

As mentioned above, the benefits of PNT services provided by GPS will accrue through the implementation of improved procedures based upon improved knowledge of aircraft position (by both pilots and controllers). This knowledge will permit more direct routing of flights with (likely, but as yet undetermined) higher spatial densities, which will result in reduced operating costs and less passenger time spent in transit. Delays will likely also be reduced. These are all benefits that have the potential to be measured accurately, since they depend on fuel saved for the airlines, and time saved for passengers. There are also expected to be efficiency benefits from the ability of controllers to handle increased traffic loads safely, although these are more uncertain. These benefits are still being quantified as part of the Next Generation (NextGen) investment analysis process.²⁷ The uncertainties concerning precisely what new procedures will be implemented, and the need to forecast equipage costs for certificated eLORAN backup systems for aircraft, along with their associated adoption rates, makes quantification challenging.

Previously, benefits were attributed to aviation by building up flight plans, assigning equipage rates, and determining savings from improved positioning that were based on phase of flight. This bottom-up approach was conservative in the sense that these efficiencies did not spill over into the aviation system at large. In other words, no multiplier was assigned to delay savings that were not propagated through the network, and so the estimate could be considered conservative. Not enough is currently known about the actual efficiency gains of NextGen from direct routing, for example, that lead to the reduction in delays, although reducing aviation delays tends to play a small part in the overall national impact.

²⁷ NextGen is the FAA's plan to modernize the U.S. National Airspace System through 2025. Through NextGen, the FAA is addressing the impact of air traffic growth by increasing NAS capacity and efficiency while improving safety, reducing environmental impacts and increasing user access to the NAS.

To better reflect the potential for gains to aviation due to introducing GPS services, the potential operational savings in using a GPS/eLORAN integrated system in general aviation and regional aircraft, as well as in some larger aircraft was examined. In terms of what likely operations may be enabled, pilots of smaller craft will be able to select and fly to alternate airports, including those currently without controlled airspace, either when GPS is disrupted or when congestion begins to delay the major carriers. Since eLORAN is intended to provide non-precision approach (NPA) capability throughout the CONUS, aircraft can then choose to fly more direct point-to-point operations when GPS service is disrupted.

It is important to recall that eLORAN has been designed and tested to meet NPA performance requirements (in support of aviation), harbor entrance and approach (in support of marine), and Stratum 1 time and frequency (in support of communications and network operations). Thus, eLORAN can meet important technical requirements of these infrastructures.

Aviation benefits will not be realized until a decision has been made to support a full build-out of eLORAN infrastructure. Following such a decision, it will take several years for industry to develop and validate suitable avionics standards. Avionics manufacturers would then develop standards-compliant equipment.

Operators would likely not be expected to retrofit for eLORAN capability alone, since eLORAN aviation capability would most likely be achieved through integrated GPS/SBAS(WAAS)/eLORAN and future dual-frequency Global Navigation Satellite System (GNSS)/eLORAN capable avionics.²⁸ With planning, this upgrade may be done in concert with other avionics or aircraft upgrades, in order to minimize added costs.

Most GPS and GPS/SBAS avionics are not upgradeable in their current configurations. Industry's non-recurring avionics development and aircraft integration costs for an integrated receiver are significant. The industry time to market for new integrated avionics will depend upon current market demand for SBAS and the timeline for future GNSS capabilities to come on line.

Operators will avoid replacing avionics until they perceive benefits that exceed the costs. Benefits are primarily achieved by equipment that enables new operational capabilities. The perception of robust availability of GPS and the existence of conventional navigational backups are disincentives to re-equip with eLORAN capable avionics.

While the positive impact of a GPS backup on congestion would be considerable under many outage scenarios, it is hard to quantify without detailed simulations. Thus, the larger picture of current aviation delays is instructive. A recent study by the Congressional Joint Economic Committee found that in 2007, \$40.7 billion in congestion

²⁸ SBAS is a general term for Satellite Based Augmentation System, while WAAS is the Wide Area Augmentation System for aviation navigation in the U.S.

costs was incurred in the U.S.²⁹ Almost twenty percent of domestic flight time was wasted in delay. One important goal of the NextGen program is to alleviate delays through direct routing and improved operational procedures as a result of GPS-based improvements in aircraft navigation and surveillance performance. Of the \$40.7 billion in congestion costs, \$19.1 billion was attributed to additional operating costs incurred by the airlines, and \$12 billion was the value of time lost to passengers, over ten million scheduled flights.

While the quantification of aviation benefits from a GPS backup must await decisions on timelines and operational specifics, the potential benefits of using a GPS back up will accrue directly based on the ability to maintain operations and efficiencies gained through use of GPS. There is also an indirect channel for benefits to accrue, through maintaining stable electrical power and communications at ground facilities in the NAS. The extent to which power and communications infrastructure is becoming increasingly reliant on GPS for timing and frequency also increases the need for a backup.

Roadway Benefits

These benefits include roadway applications such as tolling and collection of vehicle mile travelled (VMT)-based fees. Applications continue to increase. The worldwide market for roadway uses is now envisioned as 20 percent of the total land market, with “most of the rest,” around 75 percent, coming from LBS.³⁰ These applications become key as the gas tax becomes less viable as the principal source of road revenues in the U.S. The possibility of loss of service (and revenue) from GPS-reliant services points to the benefit of using a back up.³¹

Tolling services are more widely available than when the first report was written in 2004, and congestion pricing and pricing based on VMT has gone from concept to testing. In Europe, the Dedicated Short-Range Communications (DSRC) system may be overtaken by space-based services.³² Similar evaluations may be done in U.S.³³ This will likely open new markets for GPS services. Likewise, the creation of LBS and the value derived from direct routings, as described above, have greatly expanded since the 2004 BCA report. More direct routing saves gasoline, saves time for the travelers, reduces exposure to crashes, and also reduces the associated emissions. This emissions reduction creates

²⁹ See, “Your Flight Has Been Delayed Again: Flight Delays Cost Passenger, Airline, and the US Economy Billions,” in *The Economic Report of the President*, January 9, 2009, US Government Printing Office, pp.101-145.

³⁰ “Space to grow,” Philippe Hamet, in *TS International*, January/February, 2009, pp. 42-3.

³¹ See “The Case for eLORAN,” Basker et al., *General Lighthouse Authorities of the United Kingdom and Ireland*, May 8, 2006, which describes mitigating the risk of revenue loss and public confidence from road user charge apps. The availability of cheap jamming solutions available to the public will contribute to the likelihood that GPS jammers will be used.

³² *ITS International*, January/February 2009, p. 43.

³³ House Transportation and Infrastructure Chairman James Oberstar said he will push for a mileage-based tax on cars and trucks to pay for highway programs. See <http://www.rotor.com/Default.aspx?tabid=510&newsid905=61241>

benefits in air quality, and reduces associated health costs and has a positive effect on climate change.

The extent to which GPS currently contributes to direct routings and their associated savings, while conceptually quantifiable, is dependent upon penetration rates of GPS-based devices in vehicles capable of providing location services, and upon their use. There are limited data available upon which to base estimates of benefits. In particular, the increasing use of hand-held devices to provide this information, which would naturally be accounted for in the telecommunications area in terms of data transfer costs. To avoid double counting, therefore, until better information is available, this area is not separately quantified.

Critical Infrastructure Protection

In addition to the transportation and telecommunications sectors described above, the electric power grid and financial services sectors are significantly dependent upon PNT services for timing information, and consequently derive quantifiable benefits from reliable access to these services.

As described in the 2004 CBA report, increases in effectiveness (particularly robustness) and efficiency of the electric power grid are possible because of the PTTI information provided by GPS. While the risks posed by loss of the timing information through intentional or unintentional loss of PNT services is beyond the scope of a this benefit-cost analysis, it is reasonable to examine the comparative statistics of the situation in 2004 and gain an understanding of what the electric grid will likely evolve into during the analysis period. Smart Grid technology is an acceleration of the process by which advanced management of the electric power grid will enable new efficiencies and new services.³⁴ These will create additional benefits, which, while difficult to quantify, accrue as benefits to the timing services provided by an eLORAN back up under certain GPS outage scenarios.

Providing precise timing and synchronization to the financial sector was described in the previous BCA report as a benefit that could be obtained using a PNT backup system such as eLORAN. Since the last BCA report was written, it was confirmed that loss of cellular telephone service utilizing the CDMA protocol could occur within as little as about 30 minutes from the onset of jamming.³⁵ The full extent of disruption to the financial services and telecommunications sectors, and the ripple effect through the rest of the economy, is difficult to judge. In addition, the potential impact of a loss of confidence in these systems would be difficult to judge, and would have to be weighed against the practical difficulties of continuing business in a different manner.

³⁴ See, for example, "Toward a Smart Grid: Power Delivery for the 21st Century," M. Amin and B. Wollenberg, IEEE Power and Energy Magazine, Vol. 3, No. 5, Sept/Oct 2005, and the recent releases from the Department of Energy at <http://www.ferc.gov/industries/electric.asp>

³⁵ See "Global Positioning System Timing Criticality Assessment – Preliminary Performance Results," Carroll, J. and Montgomery, K., presented at the 40th Annual Precise Time and Time Interval (PTTI) Meeting, December, 2008.

In summary, the efficiency gains realized through GPS-based applications in marine shipping and logistics management account for the majority of the savings attributed to positioning and navigation. The communications services include time-stamped automatic financial transactions and direct communication of voice and data over the radio spectrum or the Internet, the latter enabling the growth in LBS. Aviation has become a major consumer of GPS services as the use of WAAS, ADS-B and other enhancements to navigation are adopted to bring about more efficient aircraft operations. Benefits also under consideration include the costs avoided due to shut down. This is in accordance with the procedures for benefit-cost analysis outlined in OMB Circular A-94.³⁶

Unquantifiable Benefits

Typically in benefit-cost analyses, the unquantified or unquantifiable benefits are relegated to a brief mention, since they do not lend themselves to expression in the final calculation. Consequently, the bottom line “net benefit” inevitably leaves the unquantified and unquantifiable benefits on the sideline. Furthermore, the redundant or backup capability potentially available from eLORAN should GPS not be available is also not always quantifiable³⁷. Moreover, the list of GPS applications continues to grow. As discussed, GPS is a critical enabling technology, and the quantifiable side of the discussion omits the value of continued growth of new applications; rather, it examines the magnitude of the loss incurred by the current services should GPS be unavailable.

Many of the most significant applications described, for example in the maritime domain, relate to safety of life and property, national security, as well as the efficiency of the economy. While benefits to commerce are quantified, the safety and security benefits are also significant. In the case of first responders, for example, timely response to the site of an automobile crash, hazardous materials spill, or impending detonation of a dirty bomb requires support from PNT services. The required communications are commonly dependent on GPS. These benefits, while significant, are not captured in a quantifiable manner, and are only incorporated qualitatively.

The State of PNT Practice

Reliance upon GPS continues to grow, and with it reports of occasional failures due both to erosion of basic navigational skills and to unplanned/inadvertent events. GPS services are generally so available that regular use allows the more traditional navigator’s skills to atrophy. GPS information is often accepted without question, even when it is faulty and

³⁶ OMB Circular A-94 provides guidance on the conduct of Benefit-Cost Analyses (BCA). It can be found at <http://www.whitehouse.gov/omb/circulars/a094/a094.html> .

³⁷ The terms *redundant*, *back up*, and *contingency* to describe a system’s mitigation capability during a GPS outage. For more information, see “Navigation and Landing Transition Strategy,” FAA ASD-1, August 30, 2002, and “Loran’s Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications,” prepared for the Federal Aviation Administration, Vice President for Technical Operations, Navigation Services Directorate, March 2004.

should be disregarded. This high level of acceptance is a mark of the success of GPS, but it is also a source of vulnerability. An alternate PNT source utilizing the same output display, obviating the need to break focus on GPS-like information, has an added cognitive benefit; it will be used and interpreted more correctly than an alternative requiring a user's acceptance of a GPS signal failure.³⁸

Retaining World Leadership in PNT

As a result of a series of decisions – technical, policy, and most importantly, financial - made over decades, the United States has attained world leadership in providing PNT services. LORAN and eLORAN were invented here. GPS was invented here. While other nations are launching their own navigation satellite constellations, there remains a worldwide tendency to look to the policies of the U.S. for guidance.

The case for eLORAN as a back up to GPS has been made and accepted in the world PNT community, and retention of the leadership role in PNT depends not only on having a robust GPS constellation, but one having the most accurate and most robust PNT service possible.³⁹ Global trade, global communications, energy provision, indeed the fabric of the economies of the developed and developing worlds, depend upon accurate and reliable U.S. PNT services.

Efficiency gains from GPS can be lost for a short time, and their effects can be compensated for in many cases. For an increasing number of GPS applications, however, the loss of timing means a total loss of services. A robust service will effectively manage unplanned service outages. It is for this reason that the Department of Homeland Security (DHS) developed a plan to mitigate interference to GPS with backup PNT services.⁴⁰ World leadership in PNT requires also the availability of an adequate backup, and that this be linked to standards in place with our trading partners.

Scenario Design Considerations

The scenarios described in the 2004 BCA report were based upon the then-current understanding of the likely jamming equipment. The previous scenarios used outage ranges from 50 miles to 200 miles for the largest intentional outage. Results of recent field tests indicate that even low power, ground based jammers can cover ranges up to about 250 miles.⁴¹ Using jammers simultaneously, as described in the most severe scenario, could easily increase the coverage area by a factor of ten, with a smaller

³⁸ See "GPS Jamming and the Impact on Maritime Navigation," Grant, A., et al, The Journal of Navigation, Vol. 62, No. 2, April 2009, pp. 173-187..

³⁹ See, for example, "The Case for eLORAN," Basker, et al., General Lighthouse Authorities of the United Kingdom and Ireland, May 8, 2006.

⁴⁰ "Positioning, Navigation, and Timing Interference Detection and Mitigation Plan," Department of Homeland Security, June, 2006.

⁴¹ "GPS Jamming and the Impact on Maritime Navigation," Grant, A., et al., The Journal of Navigation, Vol. 62, No. 2, April 2009, pp. 173-187. In addition, the US Air Force regularly conducts comprehensive GPS jamming tests ("JamFests") at White Sands Missile Range in New Mexico.

increase in the underlying population affected.⁴² It should be noted that smaller jammers are readily available (at a cost of about \$60.00) to deny GPS in a more localized area⁴³.

In this report, outage footprints from the previous analysis are retained, while noting that this is a conservative approach (See the GPS Outages section.) We also note that the use of jammers could seriously disrupt first response operations as well as other security applications not considered in the analysis. Potentially more disruptive scenarios, also not considered, are those resulting from spoofing, an insufficient satellite constellation, or unavailability of the GPS Control Segment.

The 2004 results had conservatively estimated that cellular telephone service utilizing the Code Division Multiple Access protocol (CDMA) would not be affected by loss of time synchronization until about a week after initiation. This estimate proved to be very optimistic, based on the subsequent experience of DOD-hosted GPS jamming tests and other recent experiments in maritime jamming of GPS.^{44,45} As a result, the lag between GPS disruption and loss of time synchronization is reduced from two days to as little as an hour or less.

Finally, recent experiences such as the “San Diego Incident,” during which inadvertent jamming of a GPS signal lasting about three hours fully disrupted effective use of several area cell towers, shut down a first responded pager network, and greatly limited effective use of the maritime Automated Identification System (AIS). This incident also disrupted commercial, recreational and Coast Guard vessel operations. These real-life “experiments” inform the plausibility with which this report’s outage scenarios can be viewed⁴⁶.

Costs - Baseline and Alternative LORAN Configurations

Configuration Descriptions

The alternative configurations examined cover a range of possible outcomes for LORAN, and include shutdown as well as the complete build-out of an eLORAN system with full CONUS and Alaska coverage. These are described briefly below, and in greater detail in Appendix A.

The baseline configuration against which the alternatives are measured consists of continued LORAN-C operation through fiscal year 2023 (FY2023), based on the current

⁴² Declines in population density moving out from city centers will reduce the numbers affected, if jamming is assumed to be located close to the center of populations to maximize the effect.

⁴³ See <http://www.tayx.co.uk/>

⁴⁴ See the article on GPS JamFest testing in the July/August 2008 edition of Inside GNSS.

⁴⁵ See also “GPS Jamming and the Impact on Maritime Navigation,” Grant, A., et al, The Journal of Navigation, Vol., 62, No. 2, April 2009, pp. 173-187.

⁴⁶ See “Global Positioning System Timing Criticality Assessment – Preliminary Performance Results,” Carroll, J. and Montgomery, K., presented at the 40th Annual Precise Time and Time Interval (PTTI) Meeting, 2008.

U.S. position as described in the 2008 Federal Radionavigation Plan⁴⁷ and the current USCG budget plan. If not otherwise specified, costs are assumed to incur according to a “smart” baseline principle, which assumes making intelligent and reasonable (usually cost minimizing) decisions about the continued operations of the system under study, in the absence of detailed future budget plans. In the Baseline, 24 U.S. LORAN-C LorStas (“LORAN stations”) continue to operate through 2023, and thus incur all the LORAN-related support costs. In addition to replacement of equipment and the de-staffing of all transmitter stations, Attu and Port Clarence, both in Alaska, are moved inland to take advantage of access to commercial power. The analysis includes transmitter tower replacements, based on expected service life, assuming these decisions minimize operating costs while retaining operational capabilities.

The LORAN configuration alternatives to the baseline are:

- Alternative 1 describes the case in which LORAN is terminated in all due haste. This alternative thus incurs no costs other than for operation and maintenance (O&M) through 2009, and shutdown starting in 2010. No upgrades or moves are considered.
- Alternative 2 provides for continuation and building upon the current baseline to provide partial eLORAN capability⁴⁸, maintaining current operations and capabilities, plus filling the central U.S. LORAN coverage gap with one new station. Thus, 25 LORAN-C LorStas operate through 2023, and carry all the LORAN-related support costs.
- Alternative 3 includes Alternative 2 plus full eLORAN capability, with 25 eLORAN LorStas operated thru FY2023. LORAN enhancements are described in Appendix A.

Configuration Costs

The costs of the LORAN baseline and Alternatives are shown in Table 1 and Figure 1.⁴⁹ The costs are the discounted sum of the relevant expenditures to implement the baseline and each Alternative described in Appendix A, for the period under study, the 15 year period from 2009 to 2023 inclusive.

⁴⁷ “2008 Federal Radionavigation Plan,” DOT-VNTSC-RITA-08-02/DoD-4650.5, March 2009.

⁴⁸ Most of the present LORAN infrastructure already has eLORAN components.

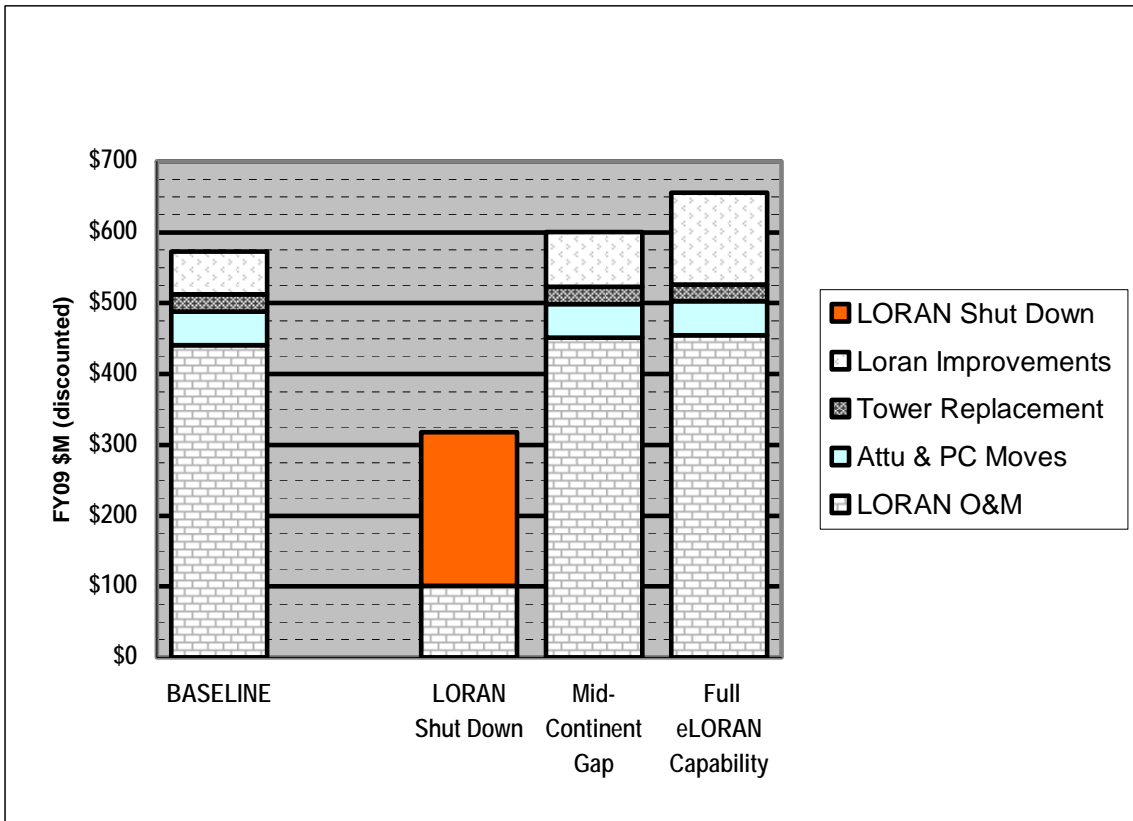
⁴⁹ These costs reflect the full operation, maintenance, and upgrades associated with each alternative. They are in 2009 dollars, with discounting to NPV done at the OMB determined rate of 1.8 percent. The Figure 1 costs are expressed in millions.

Table 1 – 2009 Present Value of Costs of LORAN and Alternatives over 2009-2023

Baseline: Continue current operation	\$573.0 million
Alternative 1: Terminate LORAN	\$318.2 million
Alternative 2: Fill Mid-Continent Gap	\$600.3 million
Alternative 3: Full eLORAN	\$655.9 million

Table 1 does not contain budget costs – rather, the then-year costs have been discounted to express their present values and then summed. While appropriate to a benefit-cost analysis, since this facilitates comparison to the present value of benefits, it reduces their usefulness for budget purposes. Real undiscounted costs are shown in Appendix C.

Figure 1 – Present Value of Costs of LORAN Baseline and Alternatives over 2009-2023



Cost avoidance is the sole benefit of shutting down LORAN (Alternative 1). As described above, it will cost \$573 million to continue LORAN on its current path of incremental upgrades and replacement. Terminating LORAN is estimated to cost \$318.2

million; thus continuing the current operations can be accomplished over the study period for the incremental cost of \$254.8 million (NPV - net present value).

Likewise, full eLORAN capability (Alternative 3) is estimated to cost \$655.9 million (NPV) over the study period, for an incremental cost of \$337.7 million over discontinuing LORAN, and for \$82.9 million compared to the cost of continuing the current operation, in NPV terms.

GPS Outage Scenarios

Scenario Descriptions

The GPS outage scenarios remain conceptually the same as in the previous analysis. Outages under study last from one day to one month, and posit jamming from a fifty-mile radius up to a 200 mile radius. This report updates their effects in order to reflect the current understanding of the impacts of GPS outages, based on recent data obtained during jamming tests and reflect telecommunications growth in the economy.

As can be seen in Table 2, the outage scenarios used are not as severe as one could imagine, based on real-world events. They are designed to represent plausible, not necessarily probable, outcomes.

Table 2 – Outage Scenarios

Scenario	Site	Radius	Duration
Unintentional	Typical city	100 miles	one week
Intentional – Low	High impact city	50 miles	one day
Intentional – Medium Impact	High impact city	100 miles	one week
Intentional - High	5 maximum impact regions	200 miles each region	one month

LORAN Benefits Quantified

As stated previously, the benefits of eLORAN derive from the ability to maintain various capabilities in the event of a GPS outage. Hence, the benefits of a backup accrue back to GPS users, not users of LORAN per se. Additionally, as stated above, it appears that there are more benefits that might be quantified with further study, as well as benefits that are amenable to quantification, even if more effort were taken. That said, the mitigation

of the loss of service from either the maritime logistics or telecommunications sectors are each sufficient to justify eLORAN as a backup to GPS if there were a large scale outage as posited in the scenarios above.

During the study period, the present value of expenditures on the full eLORAN system is estimated to be \$0.66 billion. If in the year 2020 there was a high impact outage, the loss to maritime logistics would be about \$1 billion (in today's dollars). One needs to compare that in discounted terms to the present value of the cost to maintain eLORAN, and it is important to assume that we maintain eLORAN and keep paying for it during the entire study period. Thus, comparing the discounted value of the benefits, about \$0.75 billion, with the \$0.66 billion present value of expenditures, benefits exceed costs.

Adding to this the telecommunications sector impacts, the benefits of maintaining that service is estimated at about \$1.5 billion for a high impact outage. The present value of that amount is \$1.13 billion, which also exceeds the cost of maintaining eLORAN. Limited to these two sectors, the net benefit of the backup is valued at \$1.22 billion in present value terms. The benefits that have not been quantified, but are enumerated above, are simply additive. This is not including costs that would be incurred to shut down LORAN.

Analysis

The net benefits of having a GPS back up in place are sensitive to the time period during which various scenarios take place, since more costs are incurred as time passes, while the benefits only accrue to the specific period during which the backup takes place. Our analysis thus considers the benefits of backing up a loss of GPS occurring at different times during the analysis period.

For example, the incremental cost of developing a full eLORAN capability over the study period is estimated to be \$337.7 million (NPV). (This is the cost of development of the system over the study period, less the cost of close-out.) This cost can be weighed against the benefit (in present value terms) of avoiding the losses associated with a GPS PNT outage. For the case of a Intentional High Impact outage taking place near the mid-point of the study period, in 2016, for example, the present value of avoiding such a loss is estimated at \$1.9 billion. Comparing this to the incremental cost of eLORAN over the entire study period of 15 years mentioned above, this yields a Benefit Cost Ratio of 5.6. The net benefit would be benefits less costs, or \$1.57 billion.⁵⁰ These calculations reflect only the limited set of benefits that are quantified.

There are no periods during which a high impact outage is not cost beneficial, even when restricting that aspect to the limited portion of the benefits that were quantified in the

⁵⁰ Economists strongly prefer comparing the net benefits of alternative investments. In this case, however, the comparison is not between provision of GPS back up through eLORAN or an alternative, but rather, is there a case that an eLORAN back up is cost beneficial. In that case a benefit-cost ratio in excess of unity is required to make that case.

analysis. Should no high impact outage occur during the study period, several medium scale outages would be required during the study period to make the system cost beneficial.

These benefits are due to mitigation of losses in efficiency and loss of service provision to sectors of the economy representing the modes of transportation (land, sea and air) and the telecommunications services provided to cell phone users through voice and data subscriptions. Other studies have estimated the consequences to other economies for selected outages from a GPS loss, and have placed values on the loss of the power grid, for example, which was not attempted for this analysis.⁵¹ Possible environmental consequences due to loss of critical infrastructure were not considered but, like national security, are substantial unquantified benefits of backing up a well-functioning critical infrastructure.

Summary, Conclusions and Recommendations

Summary

This assessment represents a second look, five years later, at the benefit-cost portion of the larger effort to assess the applicability of eLORAN as a backup to GPS. The benefit-cost approach was to accurately determine costs and conservatively estimate benefits against a range of possible GPS outage scenarios.

An outage is defined by the number of locations, the radius of outage, and the duration of outage. Of these, the most significant factor is duration of outage. Because eLORAN's protection against a single high impact outage event in 15 years produces a net benefit of \$1.22 billion over the study period, and there are clearly major benefits that could be added, the eLORAN system offers a cost beneficial solution as a GPS backup.

In particular, the following points are made:

- The telecommunications sector would incur the greatest financial costs during an outage and thus obtains the greatest benefit from a eLORAN backup system.
- The benefits of eLORAN exceed costs if, during the 15 year study period, two or three moderate-impact intentional GPS outages are backed-up by eLORAN.
- The benefits of eLORAN are comparable to the costs for backing-up the low-impact or unintentional GPS outage scenarios, if such events occur on average once every three months.
- LORAN is already operating, largely capitalized, and newer state-of-the-art components are part of the present LORAN system, so eLORAN would be available for the cost of completion for the recapitalization, modernization and basic operation the system. The eLORAN operating costs would be reduced through automation and

⁵¹ See, for example, eLORAN: Securing Positioning, Navigation and Timing for Europe's Future, European eLORAN Forum, April 2008.

de-staffing. The time, cost and administration required to initiate and develop a new system need not be expended.

Conclusions

eLORAN is seen to be a viable candidate back up to GPS. It is the only non-satellite PNT system that has been tested and can provide multi-modal back up for most of the PNT services GPS provides. Given the increasing importance of and dependence on PNT services, it is increasingly prudent to provide a back up to those services. Since 2004, when the first Benefit-Cost Analysis was written, the commercial services for GPS have grown into markets that were unforeseen at that time. There is little doubt that this trend will continue. The dependence of large portions of the economy on GPS PNT services remains the fundamental rationale for a viable PNT alternative, in the event of a GPS outage. It is no longer a question of if a GPS outage occurs. Rather, it is a question of when, and how prepared we are to mitigate its impact.

On the non-commercial side, the need for infrastructure protection continues. The importance of GPS services to national security, through programs such as Maritime Domain Awareness (MDA)⁵², for example, has not been quantified here. The benefits to these programs, however, are nevertheless substantial.

It is reasonable to anticipate that, by removing the uncertainty surrounding continued Federal support for eLORAN as a back up to GPS, sufficient interest would exist in supplying integrated GPS/eLORAN user equipment that such systems would become a *de facto* standard. Purchasers of such equipment would thus benefit from a built-in back up capability.

A back up for GPS reduces the risk of willful jamming by directly addressing and reducing the consequence of such an action.⁵³ System resiliency through existence of a backup PNT source such as eLORAN is a major deterrent to an intentional GPS jamming threat⁵⁴.

Recommendations

The state of the practice for benefit-cost analysis and program evaluation continues to evolve. The value from adding flexibility to project design has traditionally been difficult to quantify, and generally has been treated as an additional cost, without adequate attention paid to the benefits of preserving options. That value may come from an

⁵² See Appendix B for more information on MDA.

⁵³ The risk of an event can be defined as a likelihood coupled with an accompanying consequence. In the case of natural risks, such as fire or flood, likelihood and consequence are generally considered independent. In the case of planned events, consequence is instead a consideration in the decision to attack a target. The likelihood is addressed via the plans to mitigate GPS interference. (See, Position, Navigation, and Timing Interference Detection and Mitigation Plan, DHS, 2006.)

⁵⁴ This applies to the civil users of GPS and to a lesser degree the military uses. The degree to which it affects military users is not considered in this analysis.

additional expenditure that enables the owner to add capacity more cheaply later on, for example, or, from deferring expenditures until such time as the demand is realized.

“Real options analysis” is one methodology that has been evaluated for projects and programs in such cases.⁵⁵ One benefit of such an approach is that it overcomes the problem of using average values in interpreting systems that involve interactions of many components, leading to non-linear outcomes. Determining the option value of eLORAN, by explicitly taking into account the interaction among the many components of the infrastructure that are affected, would be a significant undertaking, but would better reflect the actual value from a GPS PNT back up. Such work is being done and is extending the practice of benefit-cost analysis.⁵⁶

⁵⁵ See, for example, the working paper by Richard de Neufville, Kenichi Hodota, Joseph Sussman, and Stefan Scholtes, “Using Real Options to Increase the Values for Intelligent Transportation Systems,” December 2008.

⁵⁶ Darren Rivey, “A Practical Method for Incorporating Real Options Analysis into US Federal Benefit-Cost Analysis Procedures,” Master’s Thesis, Massachusetts Institute of Technology, February 2007.

Appendix A

Assumptions and Alternatives

General Assumptions

- System: U.S. LORAN System (the U.S. Government does not pay for the operations of LorSta in other countries)
- Duration of study: 15-yr life-cycle cost, from FY2009 to FY2023
- Dollar base: FY09 dollars
- Discount rate: 2.75% (interpolated from rates described in OMB Circular A-94, Appendix D)
- Capital cost distribution: evenly spread over the duration of the length of the particular task
- Move Attu and Port Clarence (PC) (circa 2010): includes upgraded transmitter, signal control equipment, and environmental cleanup and remediation
- LORAN Enhancement Elements
 - Shoal Cove (pressing infrastructure repair for sustainment)
 - Legacy Solid-State Transmitter Replacement
 - Two-Way Satellite Time Transfer
 - De-staffing of transmitting stations
 - Develop Performance Work Statement & Bid Package
 - CONUS site hardening
 - Alaska site hardening
 - Tok: upgrade transmitter & signal control equipment
 - Shoal Cove: Environmental Impact Statement
 - Shoal Cove: upgrade transmitter and signal control equipment
 - Recapitalize LORAN monitor network and information control and operating system
 - LORAN Data Channel Monitor Sites (56)
 - LORAN Monitor Network Environmental Impact Statement
 - Port Surveys
 - Coverage expansion: 1 mid-continent station
 - Project Administration
- Any costs budgeted for FY08 or earlier are assumed to be sunk costs

Alternative-Specific Assumptions

- Baseline (LORAN-C operation through FY23, based on the current U.S. position as per the 2008 Federal Radionavigation Plan and current USCG plan budget. If not

⁵⁷):

- 24 LORAN-C LorSta continue to operate through 2023
 - Include all the LORAN related support costs.
 - No LORAN-C LorSta shut down
 - ALS (Automated LORAN Stations) operations in all LorSta
 - LORAN Enhancements: Shoal Cove (SC) infrastructure Repair, Legacy solid state transmitter (SSX) Replacement, and De-staffing Transmission Stations
 - Attu and PC will be moved inland to take advantage of access to commercial power (we include the costs of new stations and the decommission costs of the old stations)
 - Include tower replacement, based on the expected service life (we include LSU)
- Alternative 1 (Terminate LORAN as soon as possible):
- 24 LORAN-C LorSta thru FY09.
 - Include all the LORAN-related support costs.
 - Shut down all 24 LorSta starting FY10
 - No ALS operations
 - No LORAN enhancements
 - No Attu and PC moves
 - No tower replacement
- Alternative 2 (Baseline plus fill in mid-continent gap):
- 25 LORAN-C LorSta continue to operate through 2023
 - Include all the LORAN related support costs.
 - ALS operations in all LorSta
 - LORAN Enhancements: Shoal Cove Infrastructure Repair, Legacy SSX Replacement, De-staffing Transmission Stations, and one mid-content LorSta
 - Attu and PC will be moved inland to take advantage of commercial power (include the costs of new stations and the decommission costs of the old stations)
 - Include tower replacement, based on the expected service life (include LSU)
- Alternative 3 (Alternative 2 plus full eLORAN capability):
- 25 eLORAN LorSta thru FY2023
 - Include all the LORAN related support costs.
 - No shut down
 - ALS operations in all LorSta
 - LORAN Enhancements: Shoal Cove Infrastructure Repair, Legacy SSX Replacement, De-staffing Transmission Stations, one mid-content LorSta, Two-Way Satellite Time Transfer, Tok transmitter and signal control equipment, SC environmental impact statement, SC transmitter and signal control equipment,

⁵⁷ The concept of a so-called “smart” baseline refers to making intelligent and reasonable decisions about the continued operations of the system under study, in the absence of detailed future budget plans. This would include, for example, making prudent and necessary repairs and upgrades, without fundamentally changing the nature or mission of the system.

Monitor network and information control, and OS, LDC Monitor Sites (56), LMN Environmental Impact Statement, Port Survey, and Project Administration

- Attu and PC will be moved inland to take advantage of commercial power (we include the costs of new stations and the decommission costs of the old stations)
- Include tower replacement, based on the expected service life (include LSU)

Appendix B

Timing, Aviation Operations, and Maritime Domain Awareness

Timing

GPS is the dominant distribution source for time and frequency in the U.S. and throughout the world, and the telecommunications industry relies heavily on GPS to meet its performance requirements. GPS can provide time accurate to within 0.1 μ sec and frequency accurate to about 1×10^{-13} after 1 day of averaging. Because of its worldwide availability at very low cost, many applications and industries now use GPS exclusively as their time and frequency source, making them very vulnerable to GPS disruptions. It is generally agreed that backups and alternatives are needed to protect the national time and frequency infrastructure from the consequences of a GPS outage.

The LORAN enhancement known as eLORAN includes improvements in the key transmitter equipment, the distribution of differential corrections, and new time and frequency equipment. Using three cesium atomic clocks at each transmitter station, eLORAN can provide time synchronized to within 0.02 μ sec of Universal Coordinated Time – Stratum 1 performance comparable to, but fully independent of GPS. Calibrated receivers that apply the differential corrections were shown in tests to recover time accurate to within 0.1 μ sec⁵⁸.

Aviation Operations

Reviewer comments from FAA show concern about whether eLORAN user equipment costs are understated. The purpose of this refresh of the 2004 report is to replicate the methodology while updating cost and benefit numbers with the existing methodology and most key assumptions. The perspective has been that PNT user equipment costs certainly should be addressed in a study integrating GPS and eLORAN. For the purposes of this analysis, chip sets integrating GPS and eLORAN capability are assumed to be part of the GPS equipage, with eLORAN representing a minor share of this cost. The cost of the additional antenna has been added to this list.

Maritime Domain Awareness

Maritime Domain Awareness (MDA) is a feature of Maritime Situational Awareness, which depends more increasingly on use of GPS. Maritime situational awareness (C. Dubai, Office of MDA, USCG) is based principally on systems such as Long Range Identification and Tracking (LRIT) and the Automatic Identification System (AIS). LRIT, used by maritime nations on a global basis, provides IMO (International Maritime

⁵⁸ Lombardi, M., C. Norman, and W. Walsh, “The Role of LORAN Timing in Telecommunications,” presented at the Radio Technical Commission for Maritime Services (RTCM) annual meeting, May 2006.

Organization)-mandated ship information. LRIT is strongly dependent on GPS, as is the AIS, used by roughly 60 countries worldwide.

Appendix C

Detailed Costs (Discounted, in FY09 \$K) for Baseline and Alternatives

BASELINE	NPV	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
LORAN O&M	440,934	49,200	51,980	44,826	38,018	31,542	25,386	24,707	24,045	23,402	22,775	22,166	21,573	20,995	20,433	19,886
Attu & PC Moves	47,399	-	12,828	12,485	-	-	11,193	10,893	-	-	-	-	-	-	-	-
Tower Replacement	24,309	-	13,683	3,733	3,633	-	-	-	3,260	-	-	-	-	-	-	-
Loran Improvements	60,385	-	23,985	12,707	12,007	11,686	-	-	-	-	-	-	-	-	-	-
LORAN Shut Down	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	573,028	49,200	102,476	73,751	53,658	43,228	36,579	35,600	27,305	23,402	22,775	22,166	21,573	20,995	20,433	19,886
ALTERNATIVE 1	NPV	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
LORAN O&M	101,180	49,200	51,980	-	-	-	-	-	-	-	-	-	-	-	-	-
Attu & PC Moves	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tower Replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Loran Improvements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LORAN Shut Down	217,029	-	76,861	74,804	33,125	32,239	-	-	-	-	-	-	-	-	-	-
TOTAL	318,208	49,200	128,840	74,804	33,125	32,239	-	-	-	-	-	-	-	-	-	-
ALTERNATIVE 2	NPV	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
LORAN O&M	451,601	49,200	51,980	45,103	38,557	32,329	26,407	25,700	25,012	24,343	23,691	23,057	22,440	21,840	21,255	20,686
Attu & PC Moves	47,399	-	12,828	12,485	-	-	11,193	10,893	-	-	-	-	-	-	-	-
Tower Replacement	24,309	-	13,683	3,733	3,633	-	-	-	3,260	-	-	-	-	-	-	-
Loran Improvements	76,998	-	28,802	17,395	15,609	15,191	-	-	-	-	-	-	-	-	-	-
LORAN Shut Down	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	600,308	49,200	107,293	78,716	57,799	47,520	37,600	36,594	28,272	24,343	23,691	23,057	22,440	21,840	21,255	20,686
ALTERNATIVE 3	NPV	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
LORAN O&M	455,042	49,200	51,980	45,192	38,731	32,583	26,736	26,021	25,324	24,647	23,987	23,345	22,720	22,112	21,520	20,944
Attu & PC Moves	47,399	-	12,828	12,485	-	-	11,193	10,893	-	-	-	-	-	-	-	-
Tower Replacement	24,309	-	13,683	3,733	3,633	-	-	-	3,260	-	-	-	-	-	-	-
Loran Improvements	129,121	-	48,996	47,762	15,760	15,338	143	139	135	131	128	124	121	118	115	112
LORAN Shut Down	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	655,872	49,200	127,487	109,172	58,124	47,921	38,072	37,053	28,719	24,778	24,115	23,469	22,841	22,230	21,635	21,056

Appendix D

Detailed (Undiscounted) Benefits by Scenario and Sector

\$M	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Maritime	1.7	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6
Telecom	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Unintentional Total	2.0	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9
\$M	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Maritime	0	0	0	0	0	0	0	0	0	0	0	0
Telecom	5	5	5	5	5	5	6	6	6	6	6	6
Intentional - Low Total	5	5	5	5	5	6	6	6	6	6	6	6
\$M	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Maritime	78	79	81	83	85	87	88	90	92	94	97	99
Telecom	106	108	110	111	113	115	116	118	120	120	120	120
Intentional - Medium Total	184	187	191	194	198	201	205	209	212	214	216	219
\$M	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Maritime	829	847	866	885	904	924	945	965	987	1,008	1,031	1,053
Telecom	1,296	1,351	1,371	1,391	1,412	1,434	1,455	1,477	1,499	1,521	1,544	1,567
Intentional - High Total	2,125	2,198	2,237	2,276	2,317	2,358	2,400	2,442	2,486	2,530	2,575	2,621