Benefit-Cost Assessment Of The Use Of LORAN To Mitigate GPS Vulnerability For Positioning, Navigation, And Timing Services

Final Report

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List of Acronyms

ACG	Automatic Generation Control
ADS-B	Automatic Dependent Surveillance-Broadcast
ALS	Automated Loran System
ATIS	Advanced Traveler Information System
AVL	Automatic Vehicle Location
CDMA	Code Division Multiple Access
CE	Civil Engineering
CONUS	Conterminous United States
DME	Distance Measuring Equipment
DOT	Department of Transportation
ELC	Engineering Logistic Center
E-Loran	Enhanced-Loran
ESCR	Environmental Site Cleanup Report
FAA	Federal Aviation Administration
FY	Fiscal Year
GDP	Gross Domestic Product
GPS	Global Positioning System
GSM	Groupe Spécial Mobile
HEA	Harbor Entrance and Approach
LORAN	Long Range Navigation
LORAPP	Loran Accuracy Performance Panel
LORIPP	Loran Integrity Performance Panel
LRP	Loran Recapitalization Program
LSU	Loran Support Unit
NASD	National Association of Securities Dealers
NAVCEN	Navigation Center
NAVCENDET	Navigation Center Detachment
NPA	Non-Precision Approach
NPV	Net Present Value
NSSX	New Solid-State Transmitter
O&M	Operation and Maintenance
OMB	Office of Management and Budget
PCB	Polychlorinated Biphenyl
PNT	Position, Navigation and Time
RNAV	Area Navigation
SSX	Solid-State Transmitter
TDMA	Time Division Multiple Access

TRACEN	Training Center
TTX	Tube-Type Transmitter
USCG	U.S. Coast Guard
VOR	VHF Omnidirectional Range
WAAS	Wide Area Augmentation System

Executive Summary

PURPOSE

In 2001, a Volpe Center study assessed the vulnerability of the transportation system to loss of the Global Positioning System (GPS).[1] Subsequent to this assessment, the Secretary of the U.S. Department of Transportation initiated an examination of approaches to mitigating this vulnerability. One system-wide possibility is to modify plans for the existing LORAN system, which is currently scheduled to cease operations in 2008[2], to serve as a back-up to GPS. Within the U.S. Department of Transportation, there is a concurrent activity to provide a technical assessment of LORAN's capability to provide this mitigation. The purpose of this independent Volpe assessment is to complement the broader concurrent technical analysis of LORAN[3] by addressing the question, "Given the need to provide a GPS back-up, is enhanced LORAN more cost-beneficial than not having LORAN?"

ASSUMPTIONS

- The institution of LORAN as a back-up to GPS does not infer any safety benefits. All systems are assumed to operate such that the loss of GPS may cause a degradation of service but safety would be preserved. Thus, the analysis of benefits is focused on the efficiency gains which a LORAN back-up system would preserve.
- The study period was set at 15 years, which was deemed to be long enough to determine significant long-term effects but short enough to have believable end-state results.
- Determination of the technical adequacy of LORAN to back-up the navigation and timing users of GPS is outside the scope of the benefit-cost assessment. This is the purview of the LORAN Integrity Performance Panel (LORIPP) and LORAN Accuracy Performance Panel (LORAPP) technical committees who are addressing this question.
- This is a study of GPS users, not of LORAN users. If LORAN is to be employed as a back-up to GPS, it is the GPS users who will benefit. The GPS user community includes all modes of transportation users as well as non transportation users.
- LORAN technology will easily be integrated into GPS user equipment sets and GPS users will transition to the new integrated GPS/LORAN equipment seamlessly, and at low marginal cost.

[1] *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*; August 29, 2001; John A. Volpe National Transportation Systems Center; Cambridge MA 02142.
[2] The Federal Radionavigation Plan states that LORAN will continue to operate while DOT assesses its future. There is no policy or commitment at this time to turn it off by 2008. A decision to do so now would lead to actual shut-off in the 2008 timeframe.
[3] Except for the baseline case where LORAN is unaltered and shuts down in 2008, LORAN in this report refers to Enhanced LORAN-C and is meant to represent the system as it will be enhanced to meet new performance requirements.

- The analysis was conducted according to guidance offered in OMB (Office of Management and Budget) Circular A-94 which includes specifications of discount rates to be used.

APPROACH

Conservative Estimation of Benefits. The approach to benefits did not attempt to estimate the benefits to the entire GPS user population. To avoid speculation, sampling was confined to subsets of current GPS users and current GPS functions. Since currently, GPS is principally supplemental equipment, benefits estimated by this study represent incremental efficiency gains rather than restoration of all-or-none operations. These incremental benefits were sufficient to cover LORAN costs but in some cases provided results that were counter-intuitively low.

In aviation, for example, the study benefits were quite low. Questions about air carrier willingness to equip, and FAA's ability to shut down or reduce the number of existing back-up facilities would call into question benefit estimates based on LORAN's complete replacement of current back-ups. For example, it would be speculative to presume that the entire VOR/DME network of aviation radionavigation equipment would be shut off as a result of LORAN backing-up GPS. For aviation, therefore, this study assumed only modest flight efficiency benefits for small fractions of all sectors of aviation based on the WAAS benefit-cost study[4].

For the maritime case, the benefits were based on estimates that full use of GPS enables about a three percent gain of the flow of goods through a port. LORAN's ability to maintain that level of efficiency during a single GPS loss (high impact scenario) over the 15-year study period accounted for significant benefit.

Likewise, potential benefits were estimated for the **land mode** based on efficiency gains accruing to transit users from use of Automatic Vehicle Location (AVL) systems and the Advanced Traveler Information System (ATIS).

Timing and frequency GPS users were attributed substantial benefits because LORAN's timing precision allows CDMA[5] cell phone service to continue when the loss of GPS might cause loss of service after a one to three day period. Overall, a conservative estimate of benefits to a subset of GPS users and uses was sufficient to cover LORAN costs. A closer examination of the GPS user base could identify additional benefit accruing to LORAN as a back-up. Therefore, the conclusion was made that the case is even better made for all GPS users.

GPS Outage Scenarios. In addition to the particular uses of GPS, LORAN benefit also depends on the scope of the GPS outage which it is assumed to back-up. This study estimated a sample of benefits for each of the categories of users and developed a range

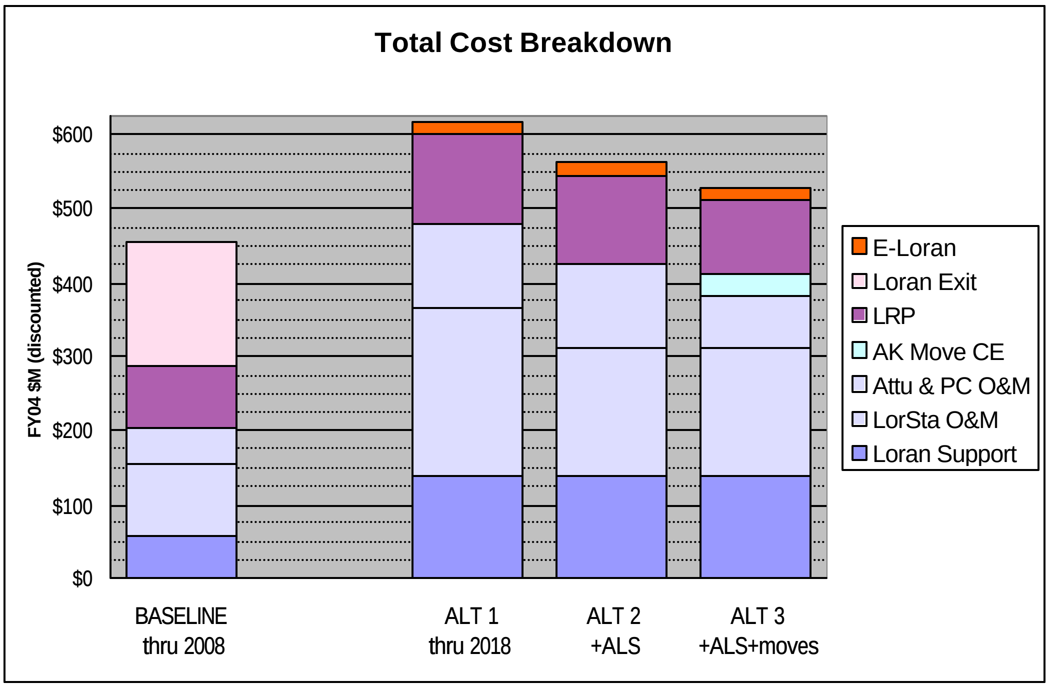
[4] Federal Aviation Administration, "Satellite Navigation Investment Analysis Report," September 25, 1999.
[5] In most cases acronyms are spelled out in the text. There is a complete list of acronyms at the end of this report.

of GPS outage scenarios to determine the limits to the benefits. As used in this study, an outage derives from the effects of some sort of local jamming of all GPS signals, and not from damage to the satellites themselves. An outage scenario is a single event over the course of the study period and is defined by the location, radius, and duration of the outage. The range of outages consisted of:

- **Unintentional** – one typical city, 100 mile radius, one week GPS loss
- **Intentional-low –** high impact city, 50 mile radius, one day GPS loss
- **Intentional-moderate** – high impact city, 100 mile radius, one week GPS loss
- **Intentional-high** – 5 high impact cities, 200 mile radius each, one month GPS loss[6]

COSTS

From a cost perspective, it is difficult to envision assembling a back-up system which would cost less than LORAN. This is due in large part to the fact that the system has already been purchased and is largely capitalized. The recapitalization of the system is well underway and the system costs relatively little to operate. Also, the prospect of



switching to an Automated LORAN System (ALS) promises to significantly reduce personnel costs, the current major operating cost element. The *Total Cost Breakdown* figure[7] shows the cost findings based on data provided by the U.S. Coast Guard on current LORAN operations. The cumulative discounted total costs are shown for each alternative summed over the study period of 15 years. On the left is the baseline case of planned shutdown of LORAN in 2008 with total discounted costs of $455M. The next bar shows that to continue to run the system through 2018 would represent a net present

[6] This extreme case is predicated on a sophisticated adversary who may provide multiple, intermittent, mobile assaults, each of which periodically interrupts service and then shuts down and relocates making apprehension a challenge.
[7] For an explanation of the cost categories see section 3.1.

value of about an additional $160M. This amount represents the costs used by this analysis for extending LORAN. The additional two alternatives show *unverified* estimates of potential additional savings which might accrue as a result of implementing the Automated LORAN System and then of relocating two of the Alaska transmitting stations. It is emphasized here that these two additional cost estimates are unverified and the impacts of these actions have not been examined.

BENEFITS

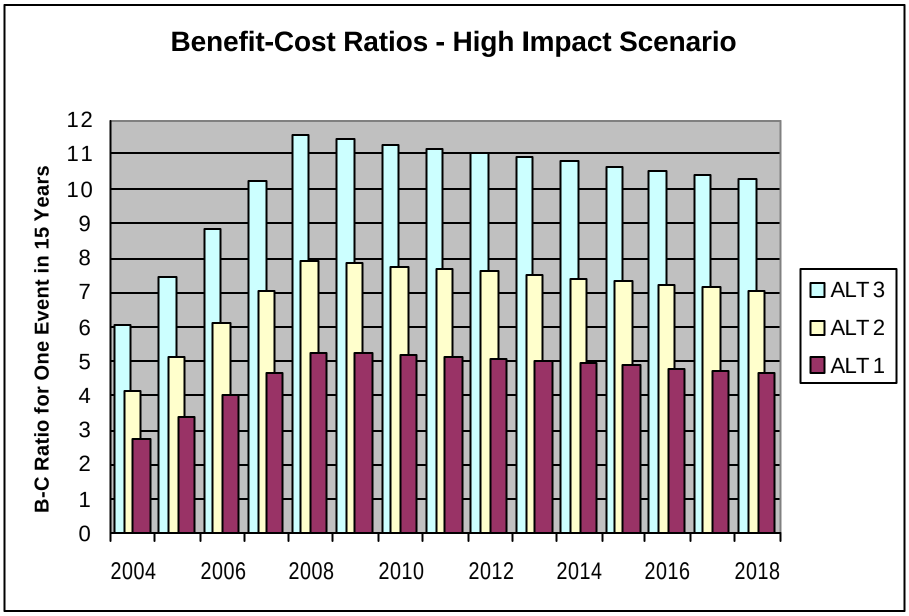
Approach To Estimation. A deliberately conservative approach was taken to estimate the benefit to GPS users of a LORAN back-up. The analysis was confined to a subset of current GPS users and current GPS applications, both from the transportation and timing communities. The analytical reasoning was that if the users and the applications were deliberately underestimated, and if LORAN was cost-beneficial under those conditions, then the overall case was indeed more so. To further constrain the case, it was not assumed that everyone studied would adopt LORAN. Rather, in most cases, a low equipage rate was used.

User Considerations. There are numerous GPS users in the United States. For this study, the categories of aviation, marine, land transportation and timing users were used. User benefits all derive from the same general approach which is described in the following way.

- User benefits derive from GPS.
- Disruption of GPS amounts to a denial of service.
- If LORAN were available as a back-up to GPS, service could be restored to users.
- Continuation of service becomes the GPS user benefit.

BENEFIT-COST ANALYSIS

In the accompanying chart, the red series of bars (lower height bars – ALT 1) represent continuing LORAN operations through 2018 and do not presume shut down of the system at that time. Alternative 2 adds the personnel savings of Automated LORAN Stations (ALS) to Alternative 1. Alternative 3 adds the savings of relocating two remote Alaskan stations to Alternative 2. Each bar represents the benefit-cost ratio if a *single* high-impact outage event were to occur in that year during the 15-year course of the study period. Thus, the range of bars displays the range of impacts based on which particular year the outage occurs. The additional bars show different assumptions for LORAN operations and include unverified estimates of operating costs and should be used only for comparison purposes. The analysis shows that the benefit-cost ratio of a single high-impact outage of GPS ranges, after the users transition, from approximately 4.7 to 5.3 depending on when the event occurs. Additional analyses not presented in this summary indicate that the moderate impact scenario generates benefit-cost ratios approximating 0.5 which suggests that the break-even point would be if LORAN were to back-up two to three moderate outages over the course of the 15-year study period. Alternatives 2 and 3 represent lower cost concepts of LORAN system operation. Although, many issues need to be resolved before they could be considered viable, the



rough cost estimates show a possibility to double the benefit cost ratios produced by Alternative 1.

CONCLUSIONS

Earlier studies have identified GPS vulnerabilities. Part of the efforts of the U.S. Department of Transportation to address these vulnerabilities is to determine whether a modernized LORAN system is adequate as a GPS back-up. This assessment represents the benefit-cost portion of the larger effort to assess the applicability of LORAN for this purpose. 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 LORAN's protection against a single high-impact outage event in 15 years produces a benefit-cost ratio in the range of 4.7 to 5.3, this assessment concludes that LORAN is clearly a cost-beneficial back-up to GPS. In particular, the following points are made:

- The benefits of LORAN exceed the costs by a factor of about 4.7 to 5.3 if, in 15 years, LORAN backs-up one high-impact GPS outage.
- The benefits of LORAN are about equally balanced by the costs if, in 15 years, two to three moderate-impact intentional GPS outages are backed-up by LORAN. Several more events would be required if a margin of error is to be provided.
- The benefits of LORAN do not approach the costs for backing-up the low-impact or unintentional GPS outage scenarios.
- Alternatives 2 and 3 represent lower cost concepts of LORAN system operation. Although, many issues need to be resolved before they could be considered viable, the rough cost estimates show a possibility to double the benefit cost ratios produced by Alternative 1.

- LORAN is already operating and largely capitalized so, as a GPS back-up, it is readily available for the cost of completion of the recapitalization, modernization and operating the system. That is, the time, cost and administrative/political initiative of developing a new system need not be expended.
- Perhaps the greatest benefit of all is not measurable. A strong back-up makes GPS a less desirable target, and reduces the risk that it would be attacked at all.

1. Introduction

1.1 Purpose

In 2001, a Volpe Center study assessed the vulnerability of the transportation system to loss of GPS.[8] Subsequent to this assessment, the Secretary of Transportation has initiated an examination of approaches to mitigate this vulnerability. One system-wide possibility is to modify the existing LORAN system, which is currently scheduled to cease operations in 2008[9], to serve as a back-up to GPS. Within the U.S. Department of Transportation (DOT), there is a significant technical effort dedicated to asses LORAN's capability to provide this mitigation. Concurrent to that effort, this independent Volpe Center assessment is meant to complement technical analyses of LORAN[10] by addressing the question, "Given the need to provide a GPS back-up, is enhanced LORAN more cost-beneficial than not having LORAN?"

This report assumed LORAN can provide an adequate back-up. The approach taken consisted of a careful examination of the cost to provide the LORAN signal and a determination of the availability of sufficient benefits to GPS users for accessing LORAN should the GPS signal become unavailable.

1.2 Background

LORAN-A was developed in the 1940's and provided principally maritime navigation services. It evolved to LORAN-C during the 1950's, saw use in aviation beginning in the 1960's and was expanded to cover the conterminous United States in the early 1990's[11].

> In 1994 DOT announced a decision to terminate LORAN in 2000 in favor of GPS-based systems. However, in the FY96 USCG Authorization Act, Congress directed the Secretary of Transportation to develop a plan for the continuation of LORAN into the next century. . . . In addition, concerns were raised about the vulnerability of GPS to jamming and a continuing need for LORAN as a back-up system to GPS, . . [12]

As a result, there is currently a comprehensive technical effort to determine the suitability of LORAN as a back-up to GPS. The technical efforts are embodied in two multi-

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[8] *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*; August 29, 2001; John A. Volpe National Transportation Systems Center; Cambridge MA 02142.

[9] The Federal Radionavigation Plan states that LORAN will continue to operate while DOT assesses its future. There is no policy or commitment at this time to turn it off by 2008. A decision to do so now would lead to actual shut-off in the 2008 timeframe.

[10] Except for the baseline case where LORAN is unaltered and shuts down in 2008, LORAN in this report refers to Enhanced LORAN-C and is meant to represent the system as it will be enhanced to meet new performance requirements.

[11] "History of Satellite Navigation," at http://ares.redsword.com/GPS/old/sum_pre.htm

[12] Radionavigation Systems: A Capabilities Investment Strategy; Radionavigation Systems Task Force; A Report to the Secretary of Transportation; January 2004; Overlook Systems Technologies, Inc.

disciplinary teams – the LORAN Integrity Performance Panel (LORIPP); and the LORAN Availability Performance Panel (LORAPP) - which will combine their efforts to submit a joint report to the U.S. Department of Transportation[13]. Summary level benefit-cost results from this current report will be included with the report of the technical panels to make a recommendation regarding the continuance of LORAN past its currently planned termination date of 2008.

1.3 LORAN As A Complement To GPS

The LORIPP and LORAPP studies examined the various technical aspects of the adequacy of LORAN to back-up GPS. While those studies will provide the technical details, it appears that LORAN has the potential to provide complementary protection against intentional GPS interference. For example:

- The GPS signal is broadcast at a very low power from satellites at a great distance, nearly 11,000 miles. The signal can be intentionally jammed by a low-power device which could be easy to implement, but could be difficult to find and eliminate. In contrast, LORAN stations broadcast from a distance less than several hundred miles, often at a power level of 500 kilowatts or more, which would make the construction of a jammer a challenge.
- The GPS signal is at a very high frequency, approximately 1.5 Gigahertz. The corresponding short wavelength then means that an interference device could be constructed with an antenna length of several inches. However, LORAN operates at 100 Kilohertz. The corresponding wavelength is 1.9 miles. Antenna lengths at LORAN stations measure from 600 feet to over 1,200 feet, so the required antenna length provides a formidable challenge to generating intentional interference.
- GPS satellites orbit the Earth and provide world-wide coverage, whereas LORAN stations are local/regional and provide several hundred miles of coverage. So, a direct attack on a satellite, although considered unlikely in the near term, has global impact, whereas the impacts of an attack on a LORAN station are necessarily restricted.
- The strength and frequency characteristics of the LORAN signal are such that it is available in places which are not in direct line with the GPS satellites, resulting in lack of GPS services. This would include some locations within buildings and in "urban canyons".

[13] The following description of the concurrent technical analysis is taken from a draft of their report: "An evaluation team comprising government agency, industry, and academic representatives conducted this evaluation. The team's focus was to determine whether LORAN-C could meet current aviation and maritime radionavigation application requirements, as well as timing/frequency requirements,[13] thus providing a viable, cost-effective alternative to the Global Positioning System (GPS) in the event of a GPS outage.[13] The position, navigation, and timing (PNT) applications evaluated include aviation navigation through non-precision approach (NPA) operations, maritime navigation through harbor entrance and approach (HEA) operations, and timing and frequency distribution through the Stratum 1 level. *The evaluation results conclude that a modernized LORAN-C system can satisfy the current NPA, HEA, and timing/frequency requirements.*"

- If LORAN as a back-up helps ensure that interfering with GPS cannot cause a major disruption, then GPS becomes less attractive as a target and, therefore, less likely to be disrupted at all.

1.4 Cost Considerations

It is difficult to envision assembling a back-up system which would cost less than LORAN. This is due in large part to the fact that the system has already been purchased and capitalized. A significant amount of the recapitalization of the system has been completed and the system costs relatively little to operate. Also, the prospect of switching to an Automated LORAN System (ALS) promises to significantly reduce personnel costs, the current major operating cost element.

1.5 User Considerations

There are numerous GPS users in the United States. This study categorized them into aviation, marine, land transportation and timing users. User benefits all derive from the same general approach, which is described in the following way:

- User benefits derive from GPS.
- Disruption of GPS amounts to a denial of service.
- If LORAN were available as a back-up to GPS, service could be restored to users.
- Continuation of service becomes the GPS user benefit.

2. Approach and Assumptions

2.1 Limitations On Use Of The Results

2.1a Sampling

The study methodology is predicated on providing a confident answer to the question, "If LORAN were used as a back-up to GPS, would it be cost-beneficial?" The determination of benefits for this question is much narrower in scope than addressing the overall benefits of LORAN as a back-up to GPS. Thus, for the purposes of this study, it was sufficient to identify sufficient benefit to exceed costs. Sampling benefits in the aviation, land, and maritime transportation modes and for the timing and frequency users provided the basis for benefits determination. This sampling, however, was not representative of all benefits and is therefore of limited application beyond answering the direct question. Had additional benefits been investigated, the benefit-cost ratio would increase since the cost of providing LORAN would be unchanged.

Consideration of the full set of user benefits is a much more difficult and involved task. This would involve making some very difficult projections in an area of rapidly evolving technology over the 15-year study period. Whereas the current study was confined to sampling a subset of current users and GPS functions, a more comprehensive analysis would need to consider the growth of GPS users and more importantly, it would need to establish what the future uses or functions of GPS would be and estimate benefits of providing a back-up for these future applications.

2.1b Efficiency Benefits

In many navigation applications, GPS provides only a supplemental capability, with more traditional methods providing the primary capability.[14] Therefore, the benefits estimated by this study represent incremental efficiency gains provided by LORAN rather than a measure of the restoration of all-or-none operations. It was determined that these incremental benefits were sufficient to cover LORAN costs while in some cases provided results that were counter-intuitively low.

In aviation, for example, the study benefits were very low in comparison to the other modes. Questions of the air carrier willingness to equip, and of the FAA's ability to shut down or reduce the number of existing back-up facilities within the study timeframe, would call into question the benefit estimates based on LORAN's complete replacement of current back-ups. For example, it would be speculative to presume that the entire VOR/DME network of aviation radionavigation equipment would be shut off as a result of LORAN backing-up GPS. It would be even more speculative to assume that the GPS-

[14] Aviation provides a useful examp le. Most existing instrument-rated GPS avionics provide only a supplemental capability, and require carriage of additional avionics compatible with legacy, ground-based radionavigation systems. GPS avionics with a primary capability to support instrument flight operations are just beginning to be developed, marketed and installed in aircraft.

based Automatic Dependent Surveillance-Broadcast (ADS-B) technology being developed as an alternative or replacement to radar surveillance will be widely deployed, and that LORAN would be employed as a GPS back-up for this application. For aviation, therefore, this study assumed only modest flight efficiency benefits for small fractions of all sectors of aviation based on the WAAS benefit-cost study. This assumption makes the aviation benefit very conservative, perhaps disproportionately so, but also makes the result robust.

For the maritime case, the benefits were based on estimates that full use of GPS enables a three percent gain of the flow of goods through a port. LORAN's ability to maintain that level of efficiency during a single GPS loss accrued substantial benefit.

Likewise, of all the potential benefit categories for the land mode, benefits were estimated based on efficiency gains to transit users from the use of Automatic Vehicle Location (AVL) systems and Automated Traveler Information Systems (ATIS).

Timing and frequency GPS users were attributed substantial benefits because LORAN's timing precision allows CDMA cell phone service to continue when the loss of GPS might cause loss of service after a one to three day period. Overall, a conservative estimate of benefits resulting from consideration of only a narrow subset of GPS users and existing GPS functions, proved sufficient to cover LORAN costs. A more comprehensive examination of the GPS user base could identify additional benefits attributable to LORAN as a back-up.

2.1c Limited Utility Of Benefits Findings

The benefits methodology developed for this study, therefore, has limited utility beyond this study. For example, since the particular benefits sampled for the study are not necessarily representative of all GPS users, it would be inappropriate to conclude that the apportionment of actual benefits to the various modes and timing GPS users is accurately reflected by the findings within this study. Such a policy level determination would require the broader, more representative approach than that required here.

2.1d Comprehensive System Costs

Costs determination, on the other hand, did not involve sampling. Rather, the costs to provide LORAN service were based on an exhaustive analysis of current and projected LORAN costs. The costs portrayed in this report represent a comprehensive enumeration of what is currently needed to improve, maintain and operate LORAN up to 15 years into the future. Therefore, in the costs chapter, sections are added to project out-year costs in inflated then-year dollars to help support those interested in the budget implications of a LORAN decision.

2.2 Major Assumptions

Several major assumptions were necessary to appropriately match the scope of the study to suit the question being asked. Major assumptions include the following:

2.2a Safety

The institution of LORAN as a back-up to GPS does not affect safety either positively or negatively. Thus the report does not discuss safety benefits. All systems are assumed to operate such that the loss of GPS will degrade service efficiency but will not compromise existing safety margins. The analysis of benefits is focused on the efficiency gains which LORAN would restore from the loss of GPS.

2.2b Duration

The study period was set at 15 years, on the basis that it would be a long enough period to accrue and measure long term effects but short enough to retain plausible end-state results.

2.2c Technical Performance

Determination of the technical adequacy of LORAN to back-up the navigation and timing users of GPS is outside the scope of the benefit-cost assessment. This is the purview of the LORIPP and LORAPP technical activities. The present study is intended to complement the technical panels and assumes that LORAN will meet the technical requirements to serve as a back-up.

2.2d User Community

There could be a natural tendency to think of this as a study of the LORAN user community, which is small compared to the number of GPS users. However, it is important to keep in mind that this is a study of LORAN as a back-up to GPS and therefore it is the GPS users who benefit. The GPS user community includes all modes of transportation users as well as timing users.

2.2e User Equipage

Separate costs for user equipage were not factored into the cost analyses. This study assumed that integrated LORAN-GPS receivers would be developed and adopted at a slow rate by the users. LORAN technology is assumed to be compatible with current GPS sets and the incremental cost of adding LORAN capability to a GPS receiver is low, probably a matter of adding the appropriate chipset and using an integrated GPS/LORAN antenna. This study also assumed that the LORAN industry is ready to support such integration once a policy to continue use of LORAN is resolved and announced.

2.2f Methodology

This analysis was conducted according to the guidance offered in OMB circular A-94 which specifies discount rates to be used in government studies.[15]

[15] **http://www.whitehouse.gov/omb/circulars/a094/a094.html**

2.3 Cost Methodology

A straightforward spreadsheet cost model was developed to tabulate LORAN costs provided by the Coast Guard. The latest available yearly costs for each of the categories were inflated to the base year of 2004. Then, using FY04 dollars, the physical infrastructure of the system was calculated and costed accordingly. The spreadsheet would then collect and appropriately discount and categorize the results.

Four basic types of costs are tracked for any particular item in the model. They are development costs, capital costs, operations and maintenance (O&M) costs, and exit costs. Development costs are incurred prior to installation and are described by an amount, the year in which they begin, and the duration of the development period. Capital, O&M and exit costs are described by an amount. O&M costs are incurred annually. Capital and exit costs are spread over a transition period. Exit costs are the costs required to close a site and include demolition and environmental cleanup. The model essentially represents a physical inventory of the infrastructure, although entries can be used to track individual cost elements as well. For each entry, or line, in the model, an initial count and up to two transitions are allowed. Each transition is described by the change number, representing how the physical count will change (delta), the year initiating the transition and the number of years the transition lasts. An example of a transition is the closing of a station which will occur in a particular year and take a certain number of years to implement. Using the initial counts of items and the transition data, the model will construct the composition of the infrastructure for each year in the study and accrue the appropriate costs. Thus, the spreadsheet is a flexible tool for tracking differing costs and cost types.

2.4 Benefit Methodology

The approach to estimating GPS user benefits was tailored to be suitable to answering the basic question of whether LORAN is a cost beneficial alternative to maintain in the event of a GPS outage. Forecasting who all the potential GPS users would be as they evolve over the next fifteen years would be beyond the scope of what would be needed to answer this question. An even broader task would be to predict all of the future functions for GPS and when they would come into prominence. The approach for this study, matched to the needs of the question, was to sample benefits from a subset of both transportation and timing users and to confine the analysis to current uses of GPS. The supposition is that if examination of a narrow subset of benefits sufficiently exceeds the costs of maintaining LORAN, then the benefit-cost case would be made even stronger for all GPS users.

While this approach is adequate for purposes of this assessment, caution must be exercised to not try to extrapolate results from the subset to the whole. That is, benefit distributions within the subset of users and functions studied may not be representative of all GPS users.

2.5 GPS Outage Scenarios

In addition to the particular uses of GPS, LORAN benefit also depends on the scope of the GPS outage that it is assumed to back-up. A sample of benefits was estimated for each of the categories of users and developed a range of GPS outage scenarios to determine the limits to the benefits. As used in this study, an outage derives from the effects of some sort of local jamming of all GPS signals, and not from damage to the satellites themselves. An outage scenario is a single event over the course of the study period and is defined by the location, radius, and duration of the outage. The rationale for selecting the scenarios was to pick a broad range of possible sets of outages to identify and capture the potential benefits under differing conditions. The range of outages considered for the study consisted of:

- **Unintentional** – one typical city, 100 mile radius, one week GPS loss
- **Intentional-low –** high impact city, 50 mile radius, one day GPS loss
- **Intentional-moderate** – high impact city, 100 mile radius, one week GPS loss
- **Intentional-high** – 5 high impact cities, 200 mile radius each, one month GPS loss

The figure below summarizes the scenario definitions.

Scenario	Site	Range	Duration
Non-Intentional	typical city	100 miles	one week
Intentional - Low	high impact city	50 miles	one day
Intentional – Moderate	high impact city	100 miles	one week
Intentional – High	five high impact cities	200 miles each city	one month

3. LORAN Costs

3.1 <u>Cost Categories</u>

3.1a Station Operations and Maintenance (except Attu, Port Clarence)

LORAN station operations and maintenance (O&M) costs in the United States include the personnel costs, the electronics equipment costs, the facility costs, the energy costs, and any other costs that insure the smooth and continuous operation of each LORAN station. Twenty-two of the twenty-four LORAN stations are included in this category.

3.1b Station Operations and Maintenance (Attu, Port Clarence)

Attu and Port Clarence LORAN stations operations and maintenance costs also include all the aforementioned costs. Attu and Port Clarence LORAN stations O&M costs are separated from the rest of the twenty-two LORAN stations to allow calculation of Alternative 3, which addresses relocation of these stations. The higher O&M costs at Attu and Port Clarence are due to the extreme conditions where these two stations are located, and relocation of these stations has been under consideration.

3.1c Support Operations and Maintenance

LORAN support O&M costs include the cost elements listed above, which support the smooth and continuous operation of LORAN. The following Coast Guard facilities are included in this category: LORAN Support Unit (LSU), Engineering Logistic Center (ELC), Training Center (TRACEN), the two Navigation Centers (NAVCEN and NAVCENDET), Headquarters, and any additional O&M costs from other support sites not accounted for.

3.1d Recapitalization Program

All costs associated with the LORAN Recapitalization Program (LRP) are captured under this category. The costs account for the upgrade of LORAN stations from tube-type transmitters (TTX) or solid-state transmitters (SSX) to the new solid-state transmitter stations (NSSX), the civil engineering costs at Alaska LORAN stations (e.g., new runways) and the replacement costs of antennas. LRP costs are incurred at all LORAN stations at the LSU, and at the TRACEN.

3.1e Exit Costs

IF, as in the Baseline case, LORAN services will be terminated in 2008, exit costs will be incurred and must be accounted for. LORAN exit costs are comprised of demolition costs and costs of environmental cleanup. Demolition costs were taken directly from Coast Guard estimates. Environmental cleanup costs were estimated by the Volpe Center and are described here.

LORAN environmental cleanup cost estimates are derived from the FAA's Fiscal Year 2003 Environmental Site Cleanup Report (ESCR), which contains the environmental cleanup costs for FAA sites around the U.S. The ESCR lists the known contaminants along with the expected total environmental cleanup cost, developed from the associated site survey, for each site. LORAN environmental cleanup costs are obtained from the cleanup costs of similar sites in the ESCR. In particular, potential contaminants at a LORAN station are investigated, based on the facilities currently on-site. From the list of potential contaminants at a LORAN station, the cleanup costs of sites from the ESCR with similar contaminants are used to bound the final estimates. A weighted average is taken to obtain the final estimates. Since there is a substantial difference in the cleanup cost between sites in Alaska and sites in the conterminous U.S. (CONUS) due to the work environment, separate estimates were developed for Alaska stations and for CONUS stations.

*Alaska stations***.** The environmental cleanup cost for Alaska stations factors in potential type of contaminants based on the current facilities at Attu, Alaska LORAN station. Below is a list of facilities and the potential type of contaminants associated with each:

- On-site medical unit - mercury
- Antenna - lead paint
- Engineering bay - solvent
- Landfill and incinerator - PCB contaminants
- Generators and fuel tank - petroleum contamination in ground water

Looking at the Alaska sites in the ESCR with similar contaminants as above, the range of environmental cleanup costs is between $5M and $10M. The average value of $7.5M is used as an estimate of Alaska station environmental cleanup cost.

*CONUS stations***.** The environmental cleanup cost for CONUS stations factors in potential type of contaminants based on the current facilities and operations at a typical CONUS LORAN station. Two scenarios are developed. A weighted average is used to develop the final estimate. The experience of Volpe staff has shown that, at similar types of sites, about 20% of CONUS sites could be heavily contaminated and the remainder would be lightly contaminated.

1. Heavily Contaminated. The potential type of contaminants associated with each station were assumed to include: lead from the paint on antennas; PCB, solvents and other contaminants in soil; and petroleum contamination in ground water from back-up generators and fuel tanks. Looking at the CONUS sites in the ESCR with similar contaminants, the range of environmental cleanup costs is estimated to be between $2M and $5M. The average value of $3.5M is used as an estimate of heavily contaminated CONUS LORAN station environmental cleanup cost.

2. Lightly Contaminated. The potential type of contaminants associated with each station were assumed to include: lead from the paint on antenna; and unknown contaminants requiring minor soil cleanup. Looking at the CONUS sites in the ESCR with similar contaminants, the range of environmental cleanup costs is between estimated to be between \$150K and \$325K. The average value of \$238K is used as an estimate of lightly contaminated CONUS LORAN station environmental cleanup cost.

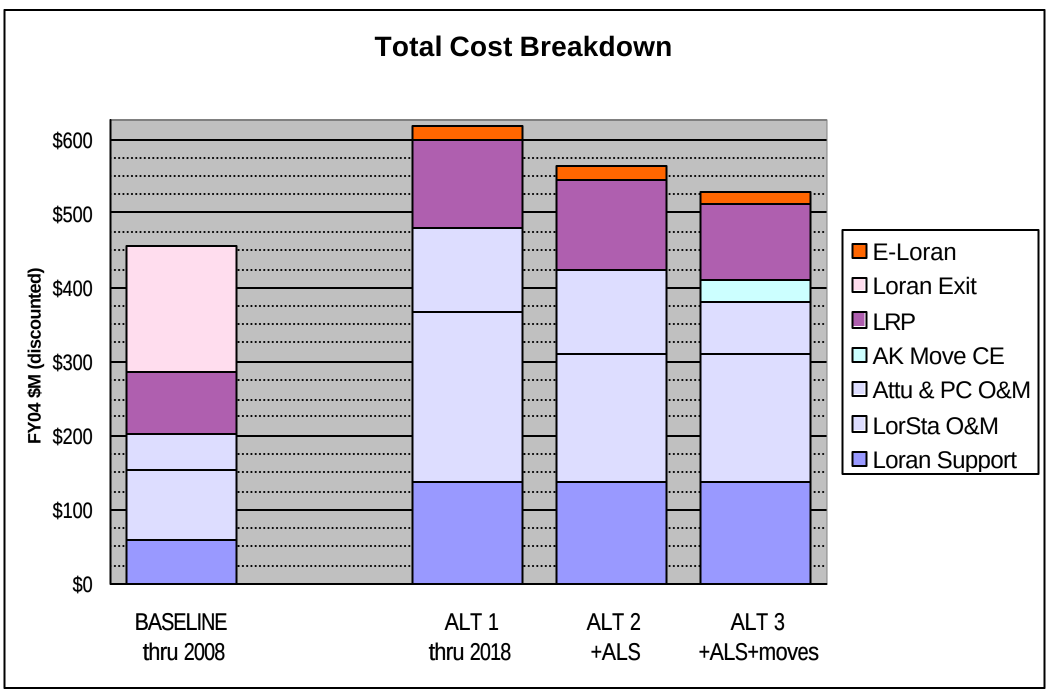
Rounding up the weighted average of the heavily and lightly contaminated CONUS LORAN stations, the figure of \$1M per station is used as the CONUS LORAN station environmental cleanup cost.

3.1f E-LORAN - 9th Pulse (Modernized LORAN)

The E-LORAN costs include items associated with LORAN enhancement to meet new performance requirements.[16] The costs include all-in-view receiver development and additional capital costs to upgrade LORAN stations. In addition, to support the enhanced LORAN for the maritime users, the cost model includes the capital and the O&M costs for additional Primary Chain Monitor Sites at 53 Class-I ports around the country, and the associated harbor survey costs.

3.2 Cost Results

The bar chart in figure, *Total Cost Breakdown*, represents the overall cost results. In each bar, the bottom three categories which are shown in differing patterns of blue represent the three components included in the operations and maintenance (O&M) category. It is



[16] Airport surveys were not included in the costs associated with E-LORAN.

interesting to note that the category, *LORAN support*, is not typically thought of as part of the O&M costs possibly because it is not associated with the operations of any particular LORAN station. However, it was included as part of the operations cost because of its necessity to the overall system operation. Understanding that LORAN may not be the sole mission of these system-wide support facilities, every effort was made to represent only those costs attributable to LORAN. The third alternative portrays a small segment labeled *AK Move CE* (civil engineering) which represents the costs of moving the two remote Alaska stations of Attu and Port Clarence to more affordable locations. The purple cross-hatched segment indicates the amount of the LORAN Recapitalization Program (LRP) that remains to be spent. Exit costs are shown in the baseline (first) bar. Finally, the top portion (red) represents the amount necessary to implement LORAN modernization, that is, improvements to the current LORAN necessary to meet new technical performance requirements (see section 3.1.f).

The FY04 discounted net present value (NPV) of baseline costs through the study period is $455M. This becomes the reference point for the benefit cost ratios. Alternative 1, represented by the first of the three grouped bars, is the official comparison point to the baseline and has an NPV of $617M. The $162M difference represents the additional cost of continuing LORAN operations through 2018.

3.3 Distinguishing Between Alternatives Two and Three

This study considered three alternative scenarios of LORAN operations. Alternatives 2 and 3 begin with the first alternative construct of operation through 2018 and then each alternative makes assumptions about different cost saving measures. Alternative 2 assumes the addition of Automated LORAN Station (ALS) operation which would allow a significant reduction of personnel and associated costs. Alternative 3 additionally assumes that two Alaska stations are relocated to less remote locations to further reduce operating costs. It is important to note that the cost estimates developed for these additional alternatives were made on simplistic assumptions of the effects of these moves. They have not been verified through the Coast Guard and the implications of such decisions have not been fully addressed. So they should not yet be considered as fully viable alternatives. Rather, they are provided to give an indication of the potential for further savings should this course of action be more fully considered.

3.3a Alternative 2 – Alternative 1 with Automated LORAN Stations (ALS) -

Besides extending LORAN operations to 2018, Automated LORAN Stations is also included in Alternative 2. ALS allows reduction of personnel at certain LORAN stations or completely remote operations at others. The appropriate capital costs, to harden the remote stations, are included. In addition, the O&M costs reflect the reduced personnel and the addition of necessary contracts to continue to support the operations at LORAN stations.

3.3b Alternative 3 – Alternative 2 with relocation of two Alaskan stations

Alternative 3 assumes the relocation of two Alaskan LORAN stations, that is, Attu and Port Clarence, in addition to converting the other 22 LORAN stations into ALS. The moves of the two LORAN stations allow them to turn into ALS due to easier access to the local electrical and transportation infrastructure. The relocation costs included the capital costs of the stations at the new location as well as the exit costs associated with the removal of the original stations. The O&M costs reflect the reduced personnel and the addition of necessary contracts to continue to support the operations at those two LORAN stations.

3.4 <u>Budgeting for LORAN: Out-year Costs</u>

The four tables at the end of this section represent an adjustment to LORAN costs derived for this report. There is a separate table for the baseline and each of the alternatives. The costs portrayed are undiscounted costs which have been inflated to *then-year dollars*. The inflation of the costs accommodates budget analysis and represents the costs of system operation referenced to the year of expenditure. All LORAN costs were derived from data obtained from the Coast Guard. The process was iterative and involved numerous exchanges to categorize and classify the various cost elements. Although all costs were provided by the Coast Guard, many were derived from multiple sources with attendant gaps and overlaps. Development of a consistent report involved extensive judgment and interpretation through numerous meetings between Coast Guard and Volpe staff. This resulted in a uniform, consistent and inclusive overview of the data appropriate for the task at hand. This is distinct from a budget perspective describing the evolution of the system. This section develops out-year budget numbers from the cost model by applying appropriate inflation factors to the constant year benefit-cost analysis numbers to frame the study results in more typical budget terms. Since these numbers reflect only a reformatting of the study numbers, they should be considered rough or approximate budget estimates and they should always be verified by the Coast Guard before being considered reliable.

In the past, estimates of what is required to operate LORAN have been organized on a station-by-station basis; there could have been a tendency to overlook the system-level support functions in estimates of the annual LORAN operating costs. These support costs are therefore listed separately in the tables. The first table shows the baseline condition of shutting down LORAN operations in 2008. The second table shows the estimates for the alternative of continuous operations through 2018. The third table addresses Alternative 2 which adds Automatic LORAN Station operations to Alternative 1. The last table adds the relocation of two Alaskan stations to less remote sites.

The inflation factors were based upon projected growth in the Gross Domestic Product (GDP) Price Index from 2004[17].

[17] Congressional Budget Office, The Budget and Economic Outlook: Fiscal Years 2005 to 2014. Note that in the report the GDP Price Index from 2008 through 2014 is given as a constant 1.9%. This study extended that constant percentage for the final four years through 2018.

BASELINE	Millions of undiscounted then-year dollars														
(thru 2008)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LorSta O&M	19	19	19	19	19	9	0	0	0	0	0	0	0	0	0
Attu & PC O&M	9	9	9	10	9	5	0	0	0	0	0	0	0	0	0
Loran Support	11	11	11	11	11	6	0	0	0	0	0	0	0	0	0
AK Move CE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loran Exit	0	0	0	0	0	71	71	32	32	0	0	0	0	0	0
E-Loran	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SubTotal	40	40	40	40	40	90	71	32	32	0	0	0	0	0	0
LRP	14	19	21	19	18	0	0	0	0	0	0	0	0	0	0
TOTAL	54	59	61	58	57	90	71	32	32	0	0	0	0	0	0

ALTERNATIVE 1	Millions of undiscounted then-year dollars														
(thru 2018)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LorSta O&M	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Attu & PC O&M	9	9	9	10	9	9	9	9	9	9	9	9	9	9	9
Loran Support	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
AK Move CE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loran Exit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E-Loran	0	6	6	1	1	1	1	1	1	1	1	1	1	1	1
SubTotal	40	46	46	40	40	40	40	40	40	40	40	40	40	40	40
LRP	14	19	22	19	18	15	14	8	2	0	0	4	4	0	0
TOTAL	54	65	67	59	58	55	54	48	42	40	40	44	44	40	40

ALTERNATIVE 2	Millions of undiscounted then-year dollars														
(2018+ALS)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LorSta O&M	19	20	18	15	13	13	13	13	13	13	13	13	13	13	13
Attu & PC O&M	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Loran Support	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
AK Move CE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loran Exit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E-Loran	0	6	6	1	1	1	1	1	1	1	1	1	1	1	1
SubTotal	40	47	44	36	34	34	34	34	34	34	34	34	34	34	34
LRP	14	19	22	19	18	15	14	8	2	0	0	4	4	0	0
TOTAL	54	66	66	55	52	48	48	42	36	34	34	38	38	34	34

ALTERNATIVE 3	Millions of undiscounted then-year dollars														
(2018+ALS+move)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LorSta O&M	19	20	18	15	13	13	13	13	13	13	13	13	13	13	13
Attu & PC O&M	9	9	9	10	6	4	4	4	4	4	4	4	4	4	4
Loran Support	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
AK Move CE	0	0	0	0	6	10	8	8	4	0	0	0	0	0	0
Loran Exit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E-Loran	0	6	6	1	1	1	1	1	1	1	1	1	1	1	1
SubTotal	40	47	44	36	37	39	37	36	32	28	28	28	28	28	28
LRP	14	19	29	19	8	4	6	4	2	0	0	4	4	0	0
TOTAL	54	66	74	56	45	43	43	40	34	28	28	33	33	28	28

4. Sampled GPS User Benefits

4.1 Benefit considerations

4.1a Approach To Estimation

Again, the deliberately conservative approach to estimating the benefit of a LORAN back-up to GPS users is emphasized. The analysis was confined to a subset of current GPS users and current GPS applications, from the transportation and timing communities. It would be challenging to accurately estimate who would be using GPS over the next 15 years and to additionally speculate on what additional uses there would be of GPS. The analytical reasoning was that if the users and the applications were systematically underestimated, and if LORAN were cost-beneficial under those conditions, then the overall case was clearly well founded. To further constrain the case, it was not assumed that all GPS users studied would adopt LORAN. Rather, in most cases, a conservatively low equipage rate was adopted.

4.1b User Considerations

The numerous GPS users were categorized as either aviation, marine, land transportation or timing and frequency users. User benefits all derive from the same general approach, which is described in the following way:

- User benefits derive from GPS.
- Disruption of GPS amounts to a denial of service.
- If LORAN were available as a back-up to GPS, service could be restored to users.
- Continuation of service becomes the GPS user benefit.

4.2 Specific Industry Uses of GPS for Timing

There are many different uses of GPS for timing. In this section, a brief discussion on some industries and applications that are using GPS, to some extent, for timing is presented. The impact of the denial of GPS service is also discussed. For some, precise timing is more critical than for others.

4.2a Telecommunication Networks[18]

Telecommunication networks are capable of providing a wide range of services, e.g., voice, data, fax, video, and encryption. To increase throughput, the telecommunication network has evolved to a synchronous digital architecture. With higher throughput, the synchronous digital network has a higher sensitivity to out-of-synchronization events.

[18] The discussion on telecommunication networks is based on:
Butterline, E., S. L. Frodge, "GPS: Synchronizing Our Telecommunications Networks," Proceedings of the 12th International Technical Meeting of the Satellite Division of the Institute of Navigation, pp.597-605, 1999.

The current telecommunication network requires Stratum 1 accuracy, which can only be provided by a cesium atomic clock, GPS, or LORAN. With poor timing synchronization, data can be detected twice or missed entirely, resulting in data corruption and service degradation. To reduce the occurrence of data corruption, time derived from the GPS signal is used to synchronize the telecommunication network. There are two major types of telecommunication networks: wire line and wireless. Without GPS timing accuracy, a wire line network would slowly degrade, starting from a week to one month's time. Voice communication is very tolerant to the degradation of synchronization but no new calls could be established. Other services, such as fax and video, which require more accurate synchronization and would not be possible once the synchronization degrades. Depending upon the type of wireless network, the amount of time to experience the impact of denial of GPS service is different. CDMA networks are more vulnerable to loss of GPS signal than GSM/TDMA networks which use wire line networks for timing synchronization. It would be one to three days before the CDMA network would experience a serious problem, whereas the GSM/TDMA network would probably work as long as a wire line network is operational.

4.2b Electric Utilities[19]

Electric utility companies use GPS timing signals to increase efficiency and enhance the integrity of the power system. If a fault occurs in the power grid, an electromagnetic wave propagates in both wire directions from the fault location. Timing of the wave arriving at a substation is recorded. By comparing the arrival times of the electromagnetic wave, the fault location can then be calculated. With GPS timing, an accuracy of 300 meters can be achieved. Without GPS timing, a secondary fault location system can help with some human intervention but is less accurate. In addition, the GPS signal is used as the reference frequency for automatic generation control (AGC), which regulates the frequency of the power grid. The reference frequency input to AGC, for example, affects clock times and machinery speeds. Moreover, unintended power exchange in the power grid could result due to less accurate reference frequency and cause reduced efficiency. If the power system is operating close to capacity, loss of the GPS signal could cause difficulty in controlling the frequency, and outages could occur.

4.2c Securities Trading[20]

Securities trading is another industry which uses GPS for timing. If a recorded value of a transaction is disputed, the time of transaction is used to resolve the dispute. More precisely, the timing information is used to correctly order the transaction among thousands or millions for proper pricing. To cope with high volume of trades, the National Association of Securities Dealers (NASD) requires its members to time stamp all transactions to within a 3-second accuracy. In reality, brokers need 5 to 20 millisecond accuracy to sort many nearly simultaneous transactions. Without GPS, a

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[19] The discussion on electric utility companies is based on:
Martin, K., "GPS Timing in Electric Power Systems," Proceedings of the 12th International Technical Meeting of the Satellite Division of the Institute of Navigation, pp.1057-1064, 1999.

[20] The discussion on securities trading is based on:
Cameron, A., "Billions per Second," *GPS World*, August 2002, pp. 38.

broker can access timing information from alternative sources without degradation of services.

4.2d Computer Networks[21]

Computer network operations, prevalent among businesses, depend on timing information. Network file sharing allows different users at different locations using client computers to access the same file centrally located at a server computer. When the server is presented with a duplicate file from a client, the time stamp of the copy on the server and on the client are compared and the copy with earlier time stamp is discarded. If there is erroneous timing on the client which results in an earlier time stamp, any changes made on the file would be discarded as well. Timing also affects the authentication process in a computer network. An encrypted authentication ticket is generated to allow a user to access services over the network. The authentication ticket is valid for a predetermined amount of time. If the clocks between network components drift beyond the predetermined authorized time, error messages can result and service could be denied. There are currently other means more common than GPS to obtain timing information for the computer networks. Therefore, a loss of the GPS signal is unlikely to affect computer network operations.

4.3 Benefit Methodology by Transportation or Timing Application

The benefit categories that were estimated for this analysis are listed within this section. For each, there is a description of the process used to derive the benefits. Where ranges of benefit estimates were possible, benefit values were selected on the conservative side of the range.

4.3a Aviation

The aviation benefit only considers the savings from the shortened flight path under instrument approach in the terminal area due to area navigation (RNAV) capability, enabled by GPS/WAAS. Benefits are accrued to air carrier, air transport, general aviation, and military craft. The aviation benefit considers the number of instrument operations affected, the amount of flight time shortened, and the value of time. The total number of projected instrument approaches for the affected city in the respective year is obtained and normalized to the duration of GPS outage by the particular outage scenario.[22] This analysis assumed that five percent of the instrument operations, based on a conservative assumption of the equipage rate, would be able to continue with the shortened flight path facilitated by the LORAN back-up. Four minutes of saving is

[21] The discussion on computer network operations is based on: Skoog, P., "The Importance of Network et/pdf/imp_netsync.pdf.

[22] Federal Aviation Administration, Terminal Area Forecast, http://www.apo.data.faa.gov/faatafall.htm

http://www.marad.dot.gov/statistics/usfwts/exp_2001.htm.
[27] Congressional Budget Office, "The Budget and Economic Outlook: An Update," August 2003, table E-1.
[28] Department of Commerce, "CEO-GPS Industry Assessment," December 1998.
[29] Federal Transit Administration, "Benefits Assessment of Advanced Public Transportation System Technologies Update 2000," November 2000.

are held constant at the 2009 level. The data from this national study is scaled to the particular scenarios, using the report's most likely fleet management systems estimates, both by population and time (to reflect the outage areas and duration of the scenarios). All transit benefits gained through GPS are assumed to be restored by LORAN back-up. These benefits are conservative, since the transit benefits are smaller compared to the projected majority of benefits in the intelligent transportation system area which are expected to derive from in-vehicle navigation systems for personal autos.

> Transit benefit = (Total annual benefit of AVL + Total annual benefit of ATIS) × (Scenario duration / 365) × (Population in the affected area / US population)

4.3d Timing and Frequency (CDMA Telecommunications)

The timing benefit only includes the CDMA cell phone users at the areas defined by the GPS outage scenarios. The benefit factors in the number of CDMA users in the affected area, the cost of CDMA service, and the length of CDMA outage. The total number of wireless users at US in 2002 is obtained and a growth rate of 9.7% is assumed.[30] The total cell phone users are capped to 80% of the projected total US population.[31] The proportion of cell phone users at the affected area is the same as in the national population. A conservative estimate of 25% of the cell phone users within the affected area is assumed to be the population of affected CDMA users. The average local monthly bill in 2002 of $48 is used as the baseline cost, which is held constant throughout the benefit study. The length of GPS outage is shortened by three days, to account for the length of time for degradation of CDMA service to fully take effect. LORAN is assumed to restore all the CDMA services at the affected region.

> Timing benefit = Wireless users at the affected area × 25% are CDMA users × Cost per day × Number of Days without CDMA services

4.4 <u>Benefits by GPS Outage Scenario</u>

Each table is stratified by mode and by year. The tables show the benefit of LORAN for a single event over the 15-year course of the study. The outage could occur at any time, so the numbers under each year show the benefit which would accrue if the outage occurred in that particular year. The benefits, therefore, are not additive across the years.

4.4a Unintentional GPS Outage

In this scenario a typical city loses GPS service for one week, due principally to interference. Because the city is not necessarily optimally placed and because the

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[30] Cellular Telecommunications and Internet Association, "Semi-Annual Wireless Survey," www.wow-com/industry/stats/surveys/.

[31] US Department of Commerce, "Methodology and Assumptions for the Population Projections of the United States: 1999 to 2100," January 2000.

Unintentional Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maritime	$M	0.6	0.9	1.2	1.5	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.7
Transit		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Telecom		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aviation		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Unintentional Total		1.0	1.3	1.7	2.0	2.3	2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.0

duration of the outage is not excessively long, the benefits are not consequential. Depending on the year of outage, LORAN provides a benefit of approximately $2M for averting a single event.

4.4b Intentional – Low Impact GPS Outage

This scenario addresses the benefit of averting a single event due to an intentional attack on GPS but it is of limited scope and duration in a single city. Basically, the impact is minimal and regardless of the year of occurrence, the impact is approximately $100K.

Low Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maritime	$M	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Trasnit		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Telecom		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Intentional - Low Total		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

4.4c Intentional – Medium Impact GPS Outage

The medium impact scenario still addresses a deliberate attack on a single high-impact city but lasts longer and has a larger scope. After transition to LORAN as a back-up, the value of a single event ranges from approximately $50M to $65M.

Medium Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maritime	$M	19.2	28.5	37.6	46.5	55.4	54.9	54.4	53.9	53.5	53.0	52.5	52.1	51.6	51.2	50.7
Transit		6.3	6.0	5.8	5.6	5.4	5.3	5.2	5.0	4.9	4.8	4.7	4.6	4.5	4.4	4.3
Telecom		8.8	9.5	10.1	10.8	11.2	11.0	10.8	10.6	10.5	10.3	10.2	10.0	9.8	9.7	9.5
Aviation		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Intentional - Medium Total		34.5	44.1	53.7	63.2	72.2	71.4	70.6	69.8	69.1	68.3	67.6	66.9	66.2	65.5	64.8

4.4d Intentional – High Impact GPS Outage

This scenario addresses the benefit of averting a single large-scale intentional attack on GPS. In this scenario, five cities selected for maximizing the effects of losing GPS are used. The duration and scope of GPS outage for the five cities are wider than in the other scenarios. The value of a single event in this case ranges from $750M to $850M, depending upon year.

High Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maritime	$M	205	304	401	497	591	586	581	576	571	566	561	556	551	546	542
Transit		99	94	91	88	86	83	81	79	78	76	74	72	71	69	67
Telecom		139	149	159	171	176	173	170	168	165	162	160	158	155	153	150
Aviation		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Intentional - High Total		444	548	653	757	853	843	833	824	814	805	796	787	778	769	760

4.5 Modal Considerations

In the development of benefits by mode, certain observations became apparent and are noted in this section.

The aviation mode, in particular, showed comparatively low benefit. Because of the necessity for back-up systems for safe aviation operations, there is already a large diverse back-up infrastructure in place so the available benefits are limited to minor efficiency gains. Although not calculated, it is likely that, if used, LORAN would provide additional benefits over the existing VOR/DME (radionavigation) back-up. This is because with VOR/DME, the pilot would constantly need to be tuning in different frequencies when GPS is lost (presuming the plane is not equipped with a flight management system). This represents an additional workload, which is a hazard, especially in stressful times like in bad weather. If the transition from GPS to LORAN is automatic in an integrated receiver, this transition would not require the manual workload and would be more beneficial. In the other modes, the existing back-up to GPS is less apparent.

For the maritime mode, since LORAN is a cross-modal system, there may be some additional inter-modal benefits for the end-to-end cargo trip. For example, LORAN would tend to back-up the full end-to-end trip of a cargo delivery from ship, into port, and then onto either rail or highway modes.

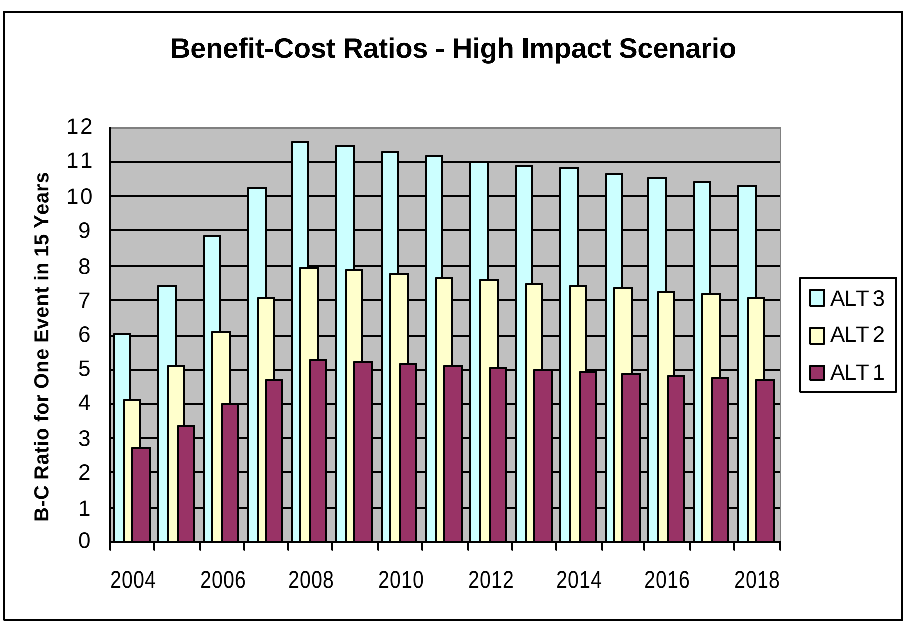
The land modes may be the most under-represented by the sampling done for the benefits analysis in this assessment. The land-mode benefits herein were based on the transit benefits deriving from automatic vehicle location systems and automatic traveler information systems. Currently, many new automobiles are being marketed with GPS-based devices that provide navigation, location, and safety response functions. As these systems become prevalent and widely relied upon, the implications for benefits of backing-up GPS for these users could become enormous.

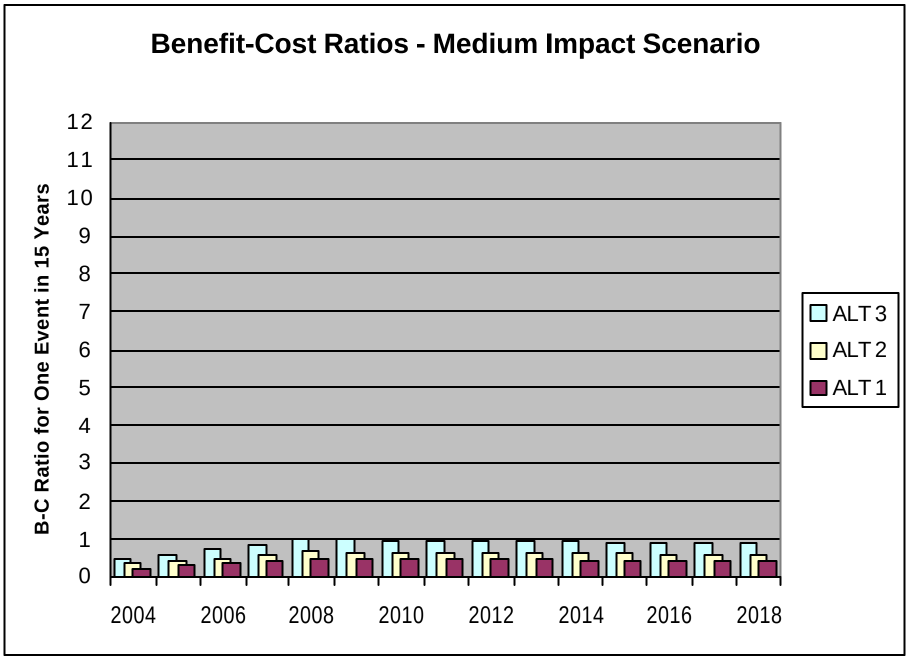
It is likely that the timing community is also largely under-represented in the currently derived benefits. This study only examined CDMA cell phone use for the telecommunications industry, and the benefit was based conservatively on the value of the phone bills. The benefit does not reflect the impacts on the growing segment of the economy dependent on cell phone use. This study also did not consider benefits to the power industry.

5. Benefit-Cost Analysis

In the accompanying charts, the lower (red) series of bars represent continuing LORAN operations through 2018 and do not presume termination of the system at that time. Each bar represents the benefit-cost ratio if a *single* outage event were to occur in that year during the 15-year course of the study period. Thus, the range of bars displays the range of impacts based on which particular year the outage occurs. The additional bars show different assumptions for LORAN operations and represent unverified estimates of operating costs and should not be regarded as official estimates. The chart shows that the benefit-cost ratio resulting from a single high-impact GPS outage ranges from approximately 4.7 to 5.3 depending on when the event occurs. Additional analyses not presented in this summary indicate that the moderate impact scenario generates benefit-cost ratios approximating 0.5 which suggests that the break-even point would be if LORAN were to back-up two moderate outages over the course of the 15-year study period.

Both the unintentional and the low-impact scenarios failed to generate significant benefit from a single event. The result was so low that multiple events in these cases would also be of inconsequential benefit. Alternatives 2 and 3 represent lower cost concepts of LORAN system operation. Although, many issues need to be resolved before they could be considered viable, the rough cost estimates show a possibility to double the benefit cost ratios produced by Alternative 1.




Benefit-Cost Ratios - Medium Impact Scenario
B-C Ratio for One Event in 15 Years
12
11
10
9
8
7
6
5
4
3
2
1
0
2004
2006
2008
2010
2012
2014
2016
2018
ALT 3
ALT 2
ALT 1

6. Conclusions

Earlier studies have identified GPS vulnerabilities. Part of the efforts of the U.S. Department of Transportation to address these vulnerabilities is to determine whether a modernized LORAN system is adequate as a GPS back-up. This assessment represents the benefit-cost portion of the larger effort to assess the applicability of LORAN for this purpose. 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 LORAN's protection against a single high-impact outage event in 15 years produces a benefit-cost ratio in the range of 4.7 to 5.3, this assessment concludes that LORAN is clearly a cost-beneficial back-up to GPS. In particular, the following points are made:

- The benefits of LORAN exceed the costs by a factor of about 4.7 to 5.3 if, in 15 years, LORAN backs-up one high-impact GPS outage.
- The benefits of LORAN are about equally balanced by the costs if, in 15 years, two to three moderate-impact intentional GPS outages are backed-up by LORAN. Several more events would be required if a margin of error is to be provided.
- The benefits of LORAN do not approach the costs for backing-up the low-impact or unintentional GPS outage scenarios.
- Alternatives 2 and 3 represent lower cost concepts of LORAN system operation. Although, many issues need to be resolved before they could be considered viable, the rough cost estimates show a possibility to double the benefit cost ratios produced by Alternative 1.
- LORAN is already operating and largely capitalized so, as a GPS back-up, it is readily available for the cost of completion of the recapitalization, modernization and operating the system. That is, the time, cost and administrative/political initiative of developing a new system need not be expended.
- Perhaps the greatest benefit of all is not measurable. A strong back-up makes GPS a less desirable target, and reduces the risk that it would be attacked at all.