Nationwide DGPS Report

Rationale for the Development of a

DGPS Policy and Implementation Plan

for a Nationwide DGPS Service

March 24, 1998

This report represents the product developed from the efforts of contributors from both the public and private sectors of our nation. Their number is too numerous to be able to furnish the names of all contributors. Therefore, it must suffice to list those individuals who have participated in central roles toward the development of a nationwide differential GPS service.

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	COST	Public Safety Benefits				Non Public Safety Benefits	
YEAR	NDGPS Cost (in Millions)	Railroad Industry Net Benefits (in Millions)	Highway Net Benefits (in Millions)	US Forest Net Benefits (in Millions)	EPA Net Benefits (in Millions)	States Net Benefits (in Millions)	Agriculture Net Benefits (in Millions)
1	$2.40	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2	$4.67	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3	$9.09	-$27.42	$60.43	$0.10	$0.10	$3.32	$51.00
4	$9.97	-$21.64	$195.10	$0.20	$0.25	$7.23	$95.32
5	$9.99	-$16.21	$320.53	$0.30	$0.38	$10.89	$133.63
6	$3.78	-$11.14	$437.19	$0.39	$0.50	$14.28	$166.52
7	$3.65	-$6.38	$545.54	$0.48	$0.61	$17.44	$194.53
8	$3.53	$21.12	$646.00	$0.48	$0.63	$17.57	$181.80
9	$3.41	$20.40	$738.98	$0.46	$0.61	$16.97	$169.91
10	$3.29	$19.71	$824.89	$0.45	$0.59	$16.39	$158.79
11	$3.18	$19.03	$904.09	$0.43	$0.57	$15.83	$148.40
12	$3.07	$18.39	$976.93	$0.42	$0.55	$15.30	$138.70
13	$2.97	$17.76	$943.67	$0.40	$0.53	$14.77	$129.62
14	$2.87	$17.16	$911.54	$0.39	$0.51	$14.27	$121.14
15	$2.77	$16.57	$880.50	$0.37	$0.49	$13.79	$113.22
Total	**$68.63**	**$67.34**	**$8,385.39**	**$4.86**	**$6.33**	**$178.05**	**$1,802.57**

15 Year Life Cycle CBA Summary	*Total*	*Ratio*
NPV of System Cost ($ M) =	*$68.63*	*1*
NPV of Public Safety related Benefits ($ M) =	*$8,463.92*	*123*
NPV of Non Public Safety related Benefits ($ M) =	*$1,980.62*	*29*
NPV of all Bnefits ($ M) =	*$10,444.54*	*152*

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Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
3	0.020	0.002	0.128	0.106
4	0.020	0.004	0.256	0.232
5	0.020	0.006	0.384	0.358
6	0.020	0.008	0.512	0.484
7	0.020	0.010	0.640	0.610
8	0.000	0.010	0.640	0.630
9 to 15	0.000	0.070	4.480	4.410
Total	**0.100**	**0.110**	**7.040**	**6.830**

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	$0.000	$0.000	$0.000	$0.000
2	$0.000	$0.000	$0.000	$0.000
3	$0.050	$0.005	$0.171	$0.116
4	$0.050	$0.010	$0.343	$0.283
5	$0.050	$0.015	$0.514	$0.449
6	$0.050	$0.020	$0.686	$0.616
7	$0.050	$0.025	$0.857	$0.782
8	$0.000	$0.025	$0.857	$0.832
9 to 15	$0.000	$0.175	$6.00	$5.83
Total	**$0.250**	**$0.275**	**$9.432**	**$8.907**

Executive Summary

Introduction and Policy Recommendation

On January 9, 1997, the US Department of Transportation initiated an effort to develop a Nationwide Differential Global Positioning System service modeled after the Coast Guard's Nationwide Differential Global Positioning System (DGPS) service. To accomplish this, the Department formed a DGPS Policy and Implementation Team and a DGPS Executive Steering Group. The Executive Steering Group provided guidance and oversight to the team during the development of the DGPS Policy and Implementation Plan. The DGPS Executive Steering Group initially met in January 1997 to discuss the development of a Policy and Implementation Plan for a Nationwide Differential Global Positioning System.

As a result of that meeting, the Steering Group requested the DGPS Policy and Implementation Team to:

- Revalidate the December, 1994 report "A Report to the Secretary of Transportation on a National Approach to Augmentation Services" (commonly referred to as the 1994 USDOT Augmentation Study),

- Identify requirements with an emphasis towards public safety,

- Examine the Presidential Decision Directive (PDD) and reconcile the augmentation study recommendations with the PDD,

- Develop a cost/benefit analysis.

Since that time, the Policy and Implementation Team has expended substantial effort in examining both the public safety and other general DGPS needs and applications.

As a result of that effort, the Policy and Implementation Team believes that there are sufficient requirements as well as compelling social and economic benefits to justify providing a Nationwide DGPS service. More importantly, there are significant public safety benefits which would warrant immediate implementation of the Nationwide DGPS service.

Background

In 1993 and 1994, several government reports identified the proliferation of GPS augmentation systems as an issue that needed to be addressed.

A December, 1993, USDOT/DOD Task Force on GPS issued a report which stated that, "...development and deployment of the optimum integrated system to provide GPS Augmentation Services is preferred."

A September, 1994, General Accounting Office (GAO) report on GPS indicated that agencies were developing augmentation systems to meet their individual agency requirements and that these augmentations were difficult if not impossible to use by other agencies.

The 1994 USDOT Augmentation Study recommended implementation of a Coast Guard-like system for use in surface applications to cover those sections of the country not currently covered by the U.S. Coast Guard DGPS service. It also recommended proceeding with the development of the Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS).

The March, 1996 Presidential Decision Directive established a Federal government policy framework for GPS. It specifically directed the Department of Transportation (USDOT) to "...develop and implement U.S. Government augmentations to the basic GPS for transportation applications."

Essentially, the aim of the DGPS Policy and Implementation Team's investigation has been to revalidate the requirements identified in the 1994 Augmentation Study and then to reconcile the recommendations of the 1994 Augmentation Study with the directions set forth in the PDD.

What is GPS?

The Global Positioning System (GPS) is a satellite-based radionavigation system developed and operated by the U.S. Department of Defense (DOD). GPS permits users to determine their three-dimensional position as well as velocity and time. The system operates 24 hours a day in all weather, anywhere in the world.

The GPS consists of a constellation of 24 satellites, a worldwide signal monitoring and control network, and a broad family of receiver equipment. Even though the GPS was originally intended to provide a military advantage for the US and its allies, it has evolved into a system that supports a broad range of civilian applications.

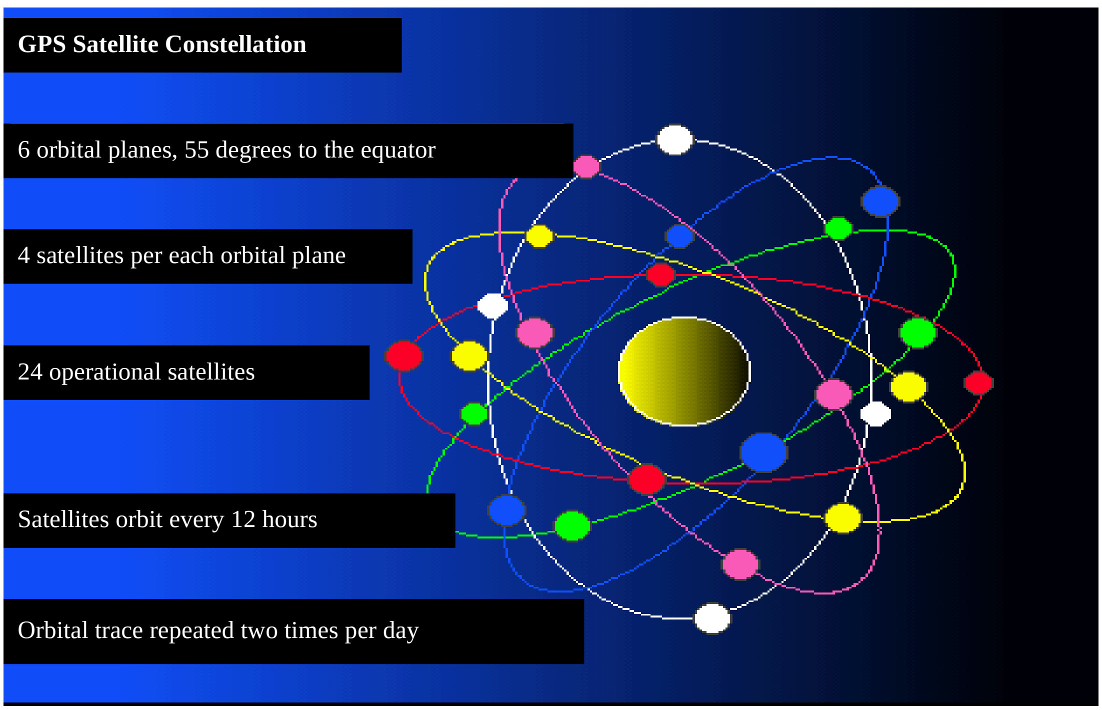

Figure I. GPS Satellite Constellation

The GPS provides two levels of service. A "Standard Positioning Service" (SPS) for general public use and an encoded "Precise Positioning Service" (PPS) primarily intended for use by the Department of Defense.

For the standard service, the signal accuracy is intentionally degraded to protect US national security interests by limiting the availability of the system's full capabilities. Both kinds of services are officially specified in the Federal Radionavigation Plan as follows:

1. The Precise Positioning Service (PPS) provides authorized users equipped with cryptographic receivers an accuracy of 22 meters (horizontal) and 27.7 meters (vertical).

2. The Standard Positioning Service (SPS) provides civil users a worldwide service without charge or restrictions. The SPS accuracy is intentionally degraded by the DOD through the use of a time-varying bias called “Selective Availability” (SA). SPS has a predictable accuracy of 100 meter (horizontal), 156 meter (vertical).

As a universal positioning system, GPS provides several characteristics not found in other existing navigation equipment, such as:

- Accurate three-dimensional position, velocity, and time data
- A worldwide common grid easily converted to other datum
- All-weather operation
- Real-time and continuous information
- Survivability in a hostile environment

How GPS Works

The principle behind GPS is the measurement of distance (or range) between a receiver and the satellites. The satellite signals also provide information as to exactly where they are situated in their orbits. They act as precise reference points. If a user knows the exact distance from at least four satellites in space, then a GPS receiver using mathematical methods can establish the user’s location on earth. Normally, a user can obtain signals from four to six satellites simultaneously.

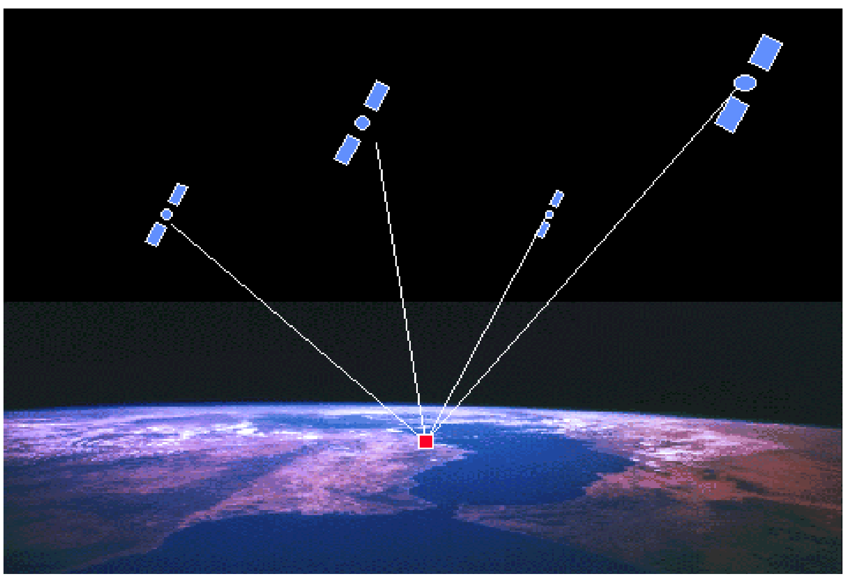

Figure II. Four Satellites in View

GPS receivers collect signals from satellites in view. They display a user's position, velocity, and time, as may be needed, for marine, terrestrial, or aeronautical applications. Some receiver units display additional data, such as distance and bearing to selected waypoints or digital charts.

What is DGPS?

To overcome the measurement error in the standard positioning service signal, the receipt of a differential correction signal can be introduced into a GPS receiver. This type of augmentation is generally referred to as a Differential Global Positioning System (DGPS). Depending on the correction method utilized, DGPS can provide an accuracy of from eight meters to better than one meter

How DGPS Works

DGPS is based upon knowledge of a highly accurate, geodetically surveyed location of a GPS reference station. This reference station observes GPS signals in real-time and compares their ranging information to the ranges expected to be observed at its fixed point. The differences between observed ranges and predicted ranges are used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed positions – See Figure III.

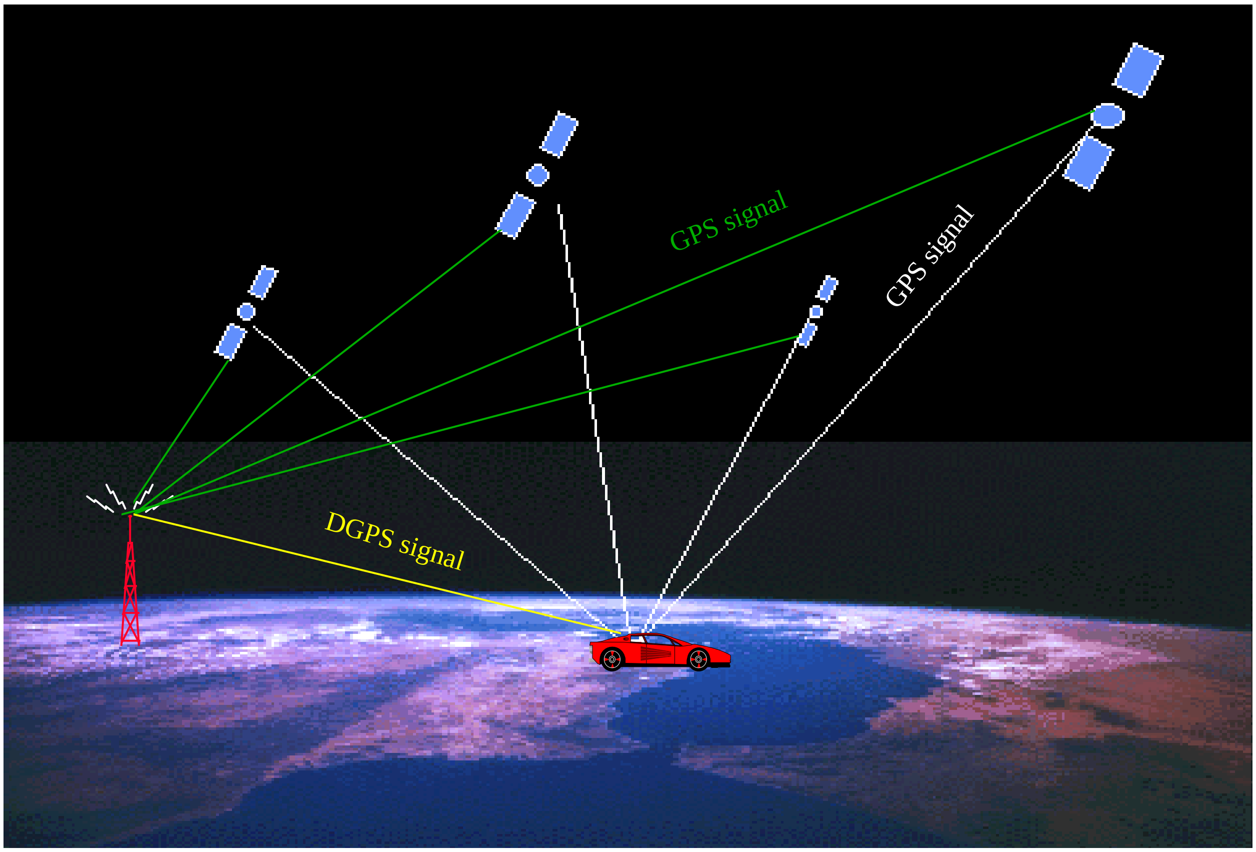

Figure III. DGPS Principle of Operation

There are several methods to broadcast a differential correction signal from a reference station to users. Some of these are:

- Geostationary satellite link
- Commercial FM subcarrier
- Radiobeacon.

Of the three methods, two are the most prevalent: Radiobeacon. which is utilized extensively by the U.S. Coast Guard/Army Corps of Engineers and geostationary satellite link which is utilized by a commercial service provider and will be the technology utilized by the FAA for its Wide Area Augmentation Service (WAAS).

Although, from a technical perspective, commercial FM subcarrier is feasible for the provision of correction signals, it has limited viability for a ubiquitous national service due to its limited range and the fundamental lack of available commercial radio stations in many areas of the country – especially in Alaska. Moreover, even among those commercial FM stations that are actively broadcasting, many stations may not make their subcarrier available for DGPS service due to its use for more lucrative business applications.

Public Safety Applications

An exhaustive search of Federal statutes turned up no codified definition of either "public safety" or "safety of life." The Team developed the following definition for public safety which is based upon the definition presented by the Public Safety Wireless Advisory Committee (PSWAC). PSWAC was established by the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration of the Department of Commerce. The original definition appears in a report submitted to the FCC and NTIA on September 11, 1996. "Public Safety" as used in this report is defined as:

> *The public's right, as prescribed by law and exercised through Federal, state or local government, or exercised through private entities that provide critical safety functions, to protect and preserve life, property, natural resources, and to serve the public welfare.*

Public safety applications for DGPS were defined as those uses that require a specified level of coverage, accuracy, availability, and integrity for a user to perform their mission functions.

Many public safety applications that would benefit from the use of DGPS were found. These included the following - Positive Train Separation (PTS), Search and Rescue operations (SAR), positioning navigational aids, law enforcement, natural resource monitoring, ground water contamination monitoring, hazardous material contamination abatement, and safety infrastructure location mapping. Each of these safety applications either saves lives directly, prevents loss of life, or reduces the chances for both near and long term public health risks.

Specific examples of public safety applications include:

- Positive Train Separation (PTS) system is being tested as a mean to reduce train accidents. PTS will identify the location of trains so that a safe distance in maintained among trains.

- EPA monitoring of water contamination requires periodic collecting of samples from various sites. As a function of this process, it is important that personnel return to the same location each time for future samples. Samples are compared over time to develop contamination trend data and plans for corrective action.

- A similar function is performed in agriculture to monitor the concentrations of fertilizers and pesticides used and thereby minimize the adverse impacts on the water supply system and the environment.

- In many cases, fire hydrants, and other public safety infrastructure, are located where they are not readily apparent in order to minimize damage due to vandalism. These assets can also become buried under snow and ice cleared from highways.

- The United States Postal Service (USPS) is concerned about tracking personnel in high crime areas or where it feels mail carriers are at risk. Locating a mail carrier quickly and precisely during a potential robbery will reduce the potential for injury or death.

- Law enforcement applications include tracking officers and vehicles to provide backup when needed.

- Emergency response and "mayday" services can benefit from DGPS by quickly locating persons with medical or other emergency service need. It is important to note that the closing of small hospitals and clinics in rural areas as a result of mergers of health care providers will have a deleterious effect on prompt care for critically injured or ill patients. To maintain a short medical response time, faster location of injured persons is important. The "golden hour of trauma" is a phrase used in the medical profession to refer to the first hour after a traumatic injury is sustained. Injured persons delivered to a medical emergency facility during this period have a much higher chance of survival. It is estimated that the use of DGPS technology to improve emergency response times could reduce the 41,000 lives lost annually on US highways by as much as 3% (1,230 lives).

- Many Federal, state and local government organizations, highlighted search and rescue (SAR) applications. Federal organizations that have SAR responsibilities, outside of law enforcement, include the US Forest Service and the National Park Service (NPS). They are often assisted by volunteer organizations such as the Amateur Radio Service, the Civil Air Patrol, and the US Coast Guard Auxiliary. Responses by many of these organizations indicated the need for a single nationwide DGPS service that provides a 10-meter accuracy that could serve rugged terrain areas as well as open land and urban areas.

Public Safety Application Requirements

Users who were contacted were most familiar with their individual accuracy requirements. Most public safety applications require accuracy on the order of 1 to 10 meters.

The most stringent system availability requirements come from the railroad industry and law enforcement. These groups need the system operating and useable for navigation or positioning 99.9% of the time.

The most stringent integrity alarm requirements come from the railroad industry, law enforcement, and natural resource monitoring users, with most users falling within the range of 10 to 20 seconds for failure notification.

Presidential Decision Directive (PDD)

The PDD identified six (6) goals that apply to this effort:

- Strengthen and maintain our national security.

  A nationwide DGPS service will reduce the number of PPS receivers needed by various civil agencies. A Federally operated nationwide DGPS service will facilitate denial by the National Command Authority of GPS and its augmentations to hostile forces in the event of a national emergency.

- Encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide.

  A Nationwide DGPS service will encourage acceptance and integration of GPS into the following applications: navigation, surveying, tracking wildlife and the spread of diseases, search and rescue, precision agriculture, and public infrastructure management.

- Encourage private sector investment in and use of US GPS technologies and services.

  Provision of a nationwide DGPS service will greatly benefit the private sector. The Nationwide DGPS Service, increasing productivity and economic growth will transform a score of industries. For example, the agriculture industry will achieve benefits estimated at a net present value of $1.8 billion during the fifteen- (15) year life cycle of the Nationwide DGPS Service.

- Promote safety and efficiency in transportation and other fields.

  The National Transportation Safety Board (NTSB) has identified implementation of PTS as one of the highest priority goals it has. The Federal Railroad Administration (FRA), in their 1995 report to Congress on PTS, stated that without nationwide DGPS service, PTS is unlikely to occur. It is also *predicted that PTS will improve efficiency, allowing the railroad industry to increase the freight capacity of the existing rail infrastructure by 25-30%.*

- Promote international cooperation in using GPS for peaceful purposes.

  Many countries have accepted the USCG DGPS service as an international standard (ITU-R M.823 and RTCM SC-104). The International Association of Lighthouse Authorities (IALA) lists 22 countries actively operating or planning compliant systems. For example, the Canadian Coast Guard is installing a radiobeacon system compatible with the USCG system, and Transport Canada officials have been very positive about implementing such a system for surface applications, especially north of the major population centers where there are large tracts of wilderness with scarce communication.

- Advance US scientific and technical capabilities.

  A freely available nationwide spatial reference system, providing a 1 to 10 meter accuracy, 99.9% availability, and a better than 10-second integrity, will provide the impetus to public and private organizations to generate a host of scientific and technical applications.

The PDD also identified the following guideline:

"To the fullest extent feasible, we will purchase commercially available GPS products and services that meet US Government requirements and will not conduct activities that preclude or deter commercial GPS activities, except for national security or public safety reasons."

Many national security and public safety applications, which require the government to operate DGPS, were identified. However, implementation of the Nationwide DGPS Service will utilize commercially available products and services to install and maintain the service. Thus, the government will, to the fullest extent feasible, purchase commercially available GPS products and services.

The PDD also directs USDOT to:

- "Serve as the lead agency within the U.S. Government for all Federal civil GPS matters."

  The Nationwide DGPS fills the requirements of many Federal agencies including FRA, EPA, DOA and DOI.

- "Develop and implement U.S. Government augmentations to the basic GPS for transportation applications."

  The Nationwide DGPS is an augmentation to the basic GPS for transportation as well as applications from other Federal civil agencies.

- "In cooperation with the Departments of Commerce, Defense and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems."

  The Nationwide DGPS uses the same standard as the Coast Guard DGPS that is one of the U.S. Government's standard augmentation systems. This standard is RTCM SC-104, which is compatible with the international ITU-R M.823 standard. The use of RTCM SC-104 in the Nationwide DGPS promotes commercial applications of this standard, which will strengthen USDOT efforts to support the standards both domestically and internationally.

- "In cooperation with other departments and agencies, coordinate U.S. Government provided GPS civil augmentation systems to minimize cost and duplication of effort.

The Nationwide DGPS will be designed to meet the needs of other departments and agencies. As a result, agencies that are currently operating small non-standard systems could phase out their systems when they are satisfied that the Nationwide DGPS meets their needs. In addition, agencies, which have a current or future need for differential corrections, would not have to build new systems.

Deployment Options for Implementation of a Nationwide DGPS Service

An investigation of implementation options to obtain a nationwide DGPS service was conducted. It is felt that the original recommendation in the 1994 report, "A Report to the Secretary of Transportation on a National Approach to Augmentation Services," for the Federal government to expand the USCG system to provide nationwide coverage is still valid.

To support this finding, the DGPS Policy and Implementation Team examined key issues related to the possible roles of the public and private sector in the expansion of the current USCG DGPS service. Inasmuch as the service expansion would be conducted in the interest of public safety, it is important to note that throughout the investigation of the various service implementation options, there was a presumption that the service is to be offered as a full and open service and the signal will be available at no cost to the end user with assured availability and integrity.

Private-Sector Implementation

One option for expanding the existing DGPS network is to rely on the private sector to implement it. This approach was deemed preferable from the viewpoint of the Federal government funding required to implement such an expansion and the lack of any requirement to maintain the system after its installation. However, there are both threshold and organizational issues that make such an approach unlikely. Threshold issues included legal prohibitions, radio frequency acquisition concerns, and, perhaps most significant, the uncertainty of a return on investment, and liability. Organizational issues include organizational form and tax liability concerns.

Public-Private Arrangements

Private Sector Consortium - One scenario considered was a critical mass of private sector entities (85% or so), with an interest in early implementation of DGPS (equipment manufacturers) and the possible commercial opportunities that could flow therefrom who would form a consortium (probably a nonprofit corporation) for the purpose of funding rapid DGPS deployment. The members could buy shares in the organization through in-kind or cash contributions and the proceeds could be provided to USDOT via an earmarked contribution for landside DGPS development. This model presents a number of problems. Obviously, the "free-rider" problem would be significant here unless there is strong industry support. Also, creation of the consortium may require a congressional exemption from anti-trust laws. This approach was deemed infeasible.

Public/Private Partnership - Alternatively, a non-profit corporation with both public and private members could be formed (possibly including state and local governments as well as Federal), such as in the HELP Inc. case. Again, the "free-rider" problem may be significant. It would involve multiple jurisdictions and would likely require a sizable staff, be time consuming, as well as unwieldy, and was also considered infeasible.

Public-Sector Implementation

State Pooled Resources - In this model, the project would be funded either as a Federal/state partnership, or solely with state funds. This model presumes a very strong State interest. From a timing perspective, it has the disadvantage or requiring coordination of multiple jurisdictions with varying procurement laws, policies and political agendas, a lengthy process at best. If the implementation of DGPS is placed solely in States' hands, it may have the added disadvantages of probably not qualifying for USCG oversight assistance, or for NTIA bandwidth. This approach would likely require a sizable staff, be time consuming and unwieldy, and was also considered infeasible

Federal Government - There are a number of arguments to support Federal government implementation and operation of a nationwide DGPS service. "Market failure" meaning the private sector would not establish a nationwide DGPS service for navigation even though currently there are private DGPS service limited to positioning. USDOT has the authority through Public Law 105-66 Section 346 to establish and operate a Nationwide DGPS Service. Moreover, Federal government agencies (the U.S. Coast Guard and Army Corps of Engineers) already operate DGPS systems. Such systems advance the mission and goals of the Department of Transportation and other Federal government agencies. Besides, only a federally owned and operated system can adhere and conform to national security guidelines and use of maritime spectrum. The public sector can realize a wide range of benefits: such as life saving, cost savings and increased efficiencies from the deployment of a nationwide DGPS service. Hazardous waste management, law enforcement, emergency services and transportation activities are the primary areas where DGPS can serve the public interest. Also, strict liability is not available against the Federal government.

Also, an opportunity to establish the additional sites relatively inexpensively is available. The US Air Force (USAF) plans to decommission its Ground Wave Emergency Network (GWEN) late in FY 1998. This presents an excellent opportunity for both the USAF and the USDOT. By reusing these sites in support of an expanded DGPS service, the USAF saves the cost of decommissioning many of its GWEN sites while the USDOT saves the cost of acquiring real estate, environmental impact studies, and capital improvements. As a result, geographic coverage of the current USCG/ACOE DGPS service could be expanded in a very short time and the cost of providing an expanded DGPS service would be significantly reduced.

Impact on Current Commercial DGPS Service Providers

Commercial DGPS service is currently offered by companies utilizing both the FM subcarrier facilities of selected commercial broadcast FM radio stations and commercial satellite facilities. These services are fee based and distinguished for the most part by their signal dissemination methods. With regard to a possible negative effect on current DGPS service providers, the expansion of the USCG service with an open signal that is provided at no cost to the end user may reduce the size of the potential market for commercial service providers. However, based upon current knowledge of the target market of theses commercial service providers as well as the ability of commercial service providers to furnish a quality of service down to the submetric positioning accuracy it is obvious that a market potential will remain.

It is worth noting that in an October 27, 1997 memorandum to Frank Raines, Director of OMB, Charles R. Trimble, Chairman of the U.S. GPS Industry Council stated "...some private sector models are more successful than others. .... the use of the FM subcarrier proved not to be reliable in the field. This lack of performance to the customer has driven the private FM subcarriers to their current economic state, NOT the threat of competition from the U.S. government. ......From our industry perspective, it would be a severe disservice to the U.S. taxpayer to impede the implementation of a nationwide DGPS, especially in such a cost effective manner"

Conclusion

The provision of a standardized nationwide DGPS service will have a beneficial effect on the national ability to provide improved public safety capabilities as well as accelerate technology improvements in the GPS/DGPS industry segment. Additionally, there is every reason to presuppose that synergistic benefits will be enjoyed by the national economy through improved efficiencies in areas such as public safety, transportation, geodetic services, and agriculture.

Although there are a number of methods that could possibly be utilized to implement and maintain a nationwide DGPS service as a utility, the most practical approach is to implement a service that is installed and maintained by the Federal government. The installation period will be shorter and assurance of compliance with nationally and internationally recognized standards is guaranteed.

Benefits and Costs

The benefits of providing a nationwide DGPS service are real and substantial but difficult to quantify in some cases. An assumption is made that generally it will take at least two years after the start of implementation of a nationwide DGPS service before users will realize any significant benefits from a universal DGPS service. This assumption is predicated on the belief that the DGPS service expansion will be a phased implementation as well as the fact that users will require a period of time to become aware of DGPS service availability and to acquire any additional enabling technology in order to utilize the service. Therefore, zero economic benefits are assumed for the first two years after providing service availability in those geographical areas not currently covered by the USCG/ACOE DGPS service.

NTSB Chairman Jim Hall, in a speech in June 1996, estimated that the savings due solely to train accidents that could be avoided with PTS would have been on the order of $60 million in property damage for the first half of 1996.

Law enforcement and professional as well as amateur search and rescue organizations identified many instances where, due to rough terrain and poor visibility, it was difficult to ensure that search operations were thorough. They believe DGPS can save lives.

The US Forest Service has the potential to save an estimated net present value of $ 4.86 million during the fifteen year life cycle of the system. An example is the efficiency increase in firefighting by using real-time DGPS corrections to support Geographic Information System (GIS) databases and digital maps for the command and control of fire fighting aircraft.

The estimated net present value of savings during the fifteen year life cycle of the system for the monitoring functions of the Environmental Protection Agency (EPA) is estimated to be $6.33 million through using real-time DGPS instead of post processing DGPS.

Consistent with requirements of Office of Management and Budget (OMB) Circular A-94, the DGPS Policy and Implementation Team looked at a number of relevant benefits. It is most striking that the agricultural industry alone has the potential to realize savings estimated at a net present value of $1.8 billion during the fifteen year life cycle of the system through the use of a technique known as “precision agriculture.” This application of DGPS has the added benefit of reducing the quantity of herbicides, insecticides and fertilizer thus decreasing their adverse environmental impact. The ever increasing number of DGPS applications makes it nearly impossible to capture all of the benefits. But in the three months that the DGPS Policy and Implementation Team spent researching issues for this report, it has identified enormous savings both in terms of lives saved and improved efficiencies. Using the OMB Circular A-94 method of determining life cycle benefits, the net present value of benefits over the 15-year life cycle for the Nationwide DGPS Service is over $10 billion.

The capital cost to complete nationwide coverage of an LF/MF Radiobeacon DGPS signal is estimated to be between $28.62 million and $37.62 million, depending on which of three options is used. The two lower cost opportunities involve taking advantage of US Air Force (USAF) plans to decommission its Ground Wave Emergency Network (GWEN) late in FY 1998. These two options save the USAF some of the costs associated with decommissioning the GWEN system while also decreasing the cost to install a Nationwide DGPS. Annual operating and maintenance costs for the sites necessary to complete nationwide coverage are expected to be approximately $4.66 million. Again using the OMB Circular A-94 method of determining life cycle costs, the 15-year life cycle cost of the Nationwide DGPS Service is estimated to be $68.63 million.

Since the $10.44 billion life cycle benefits far outweigh the $68.63 million life cycle cost, the team strongly recommends that the Nationwide DGPS be implemented.

1. OBJECTIVES

The focus of the study effort associated with development of this report has been to reexamine the expansion of the current US Coast Guard (USCG) low frequency/medium frequency (LF/MF) radiobeacon Differential Global Positioning System (DGPS) to a nationwide service in the context of the policy guidelines of the Presidential Decision Directive (PDD).

The objective of the study is to evolve a DGPS Policy and Implementation Plan that will be used to expand the current coverage of the USCG DGPS service into a Nationwide DGPS service. In order to do this, several specific items are addressed in this report. These include:

- Revalidate the December, 1994 report "A Report to the Secretary of Transportation on a National Approach to Augmentation Services" (commonly referred to as the 1994 USDOT Augmentation Study),
- Identify land navigation and positioning requirements with an emphasis toward public safety,
- Examine the Presidential Decision Directive (PDD) and reconcile the 1994 USDOT augmentation study recommendations with the PDD policy guidelines and direction,
- Develop a cost/benefit analysis for provision of a nationwide DGPS service.

2. BACKGROUND

2.1 Responsibilities

The United States Department of Transportation (USDOT) has been designated by the President to represent the Nation's civilian interests in the use of the Global Positioning System (GPS). USDOT recognizes that there is substantial benefit in the establishment of services to meet Federal user requirements for positioning and navigation on the sea, on the land and in the air. This report is the culmination of a series of tasks undertaken by USDOT to determine the most appropriate technical and economic approach to satisfy Federal user requirements and national requirements for public safety.

2.2 History

One of the first efforts to identify issues associated with GPS was the 1993 Joint Task Force report. This effort examined the extent to which the Federal government should centralize development and operation of government-provided GPS. It recommended "the development and deployment of the optimum integrated system to provide GPS augmented services."[1] It was recognized that many Federal agencies were developing augmentation systems to meet their specific requirements and were not coordinating with other agencies.

[1] The Global Positioning System: Management and Operation of a Dual Use System, Joint DOD/DOT Task Force, A report to the Secretaries of Defense and Transportation, December 1993, page 43.

In September 1994, the General Accounting Office (GAO) published a report[2] that was critical of the number of augmentation systems Federal agencies were developing. The GAO noted that "incompatible equipment and inconsistent operating procedures"[3] discouraged agencies from using another agency's DGPS services. However, the report complemented the cooperative efforts of the National Oceanic and Atmospheric Administration (NOAA), US Army Corps of Engineers (ACOE), and US Coast Guard (USCG), to modify the Coast Guard DGPS system to meet other agencies' needs.

2.3 What is GPS?

The Global Positioning System (GPS) is a satellite-based radionavigation system developed and operated by the U.S. Department of Defense (DOD). GPS permits users to determine their three-dimensional position as well as velocity and time. The system operates 24 hours a day in all weather, anywhere in the world.

The GPS consists of a constellation of 24 satellites, a worldwide signal monitoring and control network, and a broad family of receiver equipment. Even though the GPS was originally intended to provide a military advantage for the US and its allies, it has evolved into a system that supports a broad range of civilian applications.

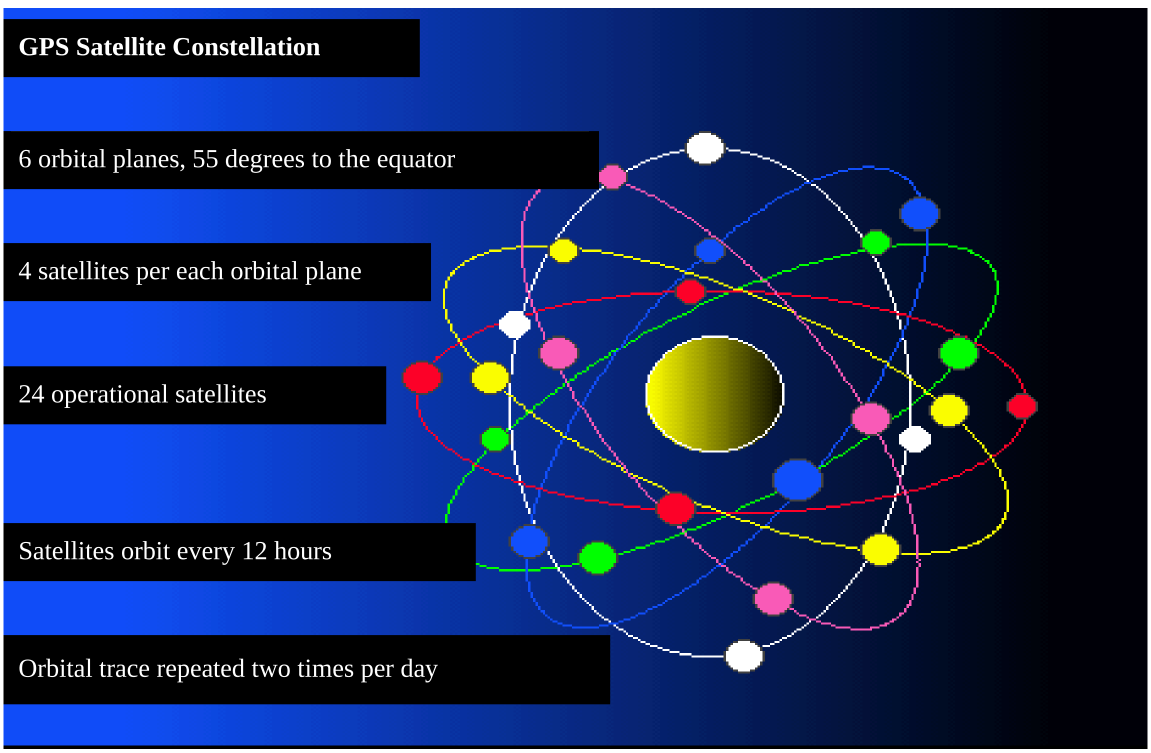

Figure 1. GPS Satellite Constellation

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[2] Global Positioning Technology, Opportunities for Greater Federal Agency Joint Development and Use, GAO/RCED-94-280, General Accounting Office, September 1994.

[3] Global Positioning Technology, Opportunities for Greater Federal Agency Joint Development and Use, GAO/RCED-94-280, General Accounting Office, September 1994, page 8.

The GPS provides two levels of service. A "standard positioning service" (SPS) for general public use and an encoded "precise positioning service" (PPS) primarily intended for use by the Department of Defense.

For the standard service, the signal accuracy is intentionally degraded to protect US national security interests by globally limiting the availability of the system's full capabilities. Both kinds of services are officially specified in the Federal Radionavigation Plan as follows:

1. The Precise Positioning Service (PPS) provides authorized users equipped with cryptographic receivers an accuracy of 22 meters (horizontal) and 27.7 meters (vertical).

2. The Standard Positioning Service (SPS) provides civil users a worldwide service without charge or restrictions. The SPS accuracy is intentionally degraded by the DOD through the use of a time-varying bias called "Selective Availability" (SA). SPS has a predictable average accuracy of 100-meter (horizontal), 156 meter (vertical).

As a universal positioning system, GPS provides several characteristics not found in other existing navigation equipment, such as:

- Accurate three-dimensional position, velocity, and time data
- A worldwide common grid easily converted to other data
- All-weather operation
- Real-time and continuous information
- Survivability in a hostile environment

2.3.1 How GPS Works

The principle behind GPS is the measurement of distance (or range) between a receiver and the satellites. The satellite signals also provide information as to exactly where they are situated in their orbits. They act as precise reference points. If a user knows the exact distance from at least four satellites in space, then a GPS receiver using mathematical methods can establish the user's location on earth. Normally, a user can obtain signals from four to six satellites simultaneously.

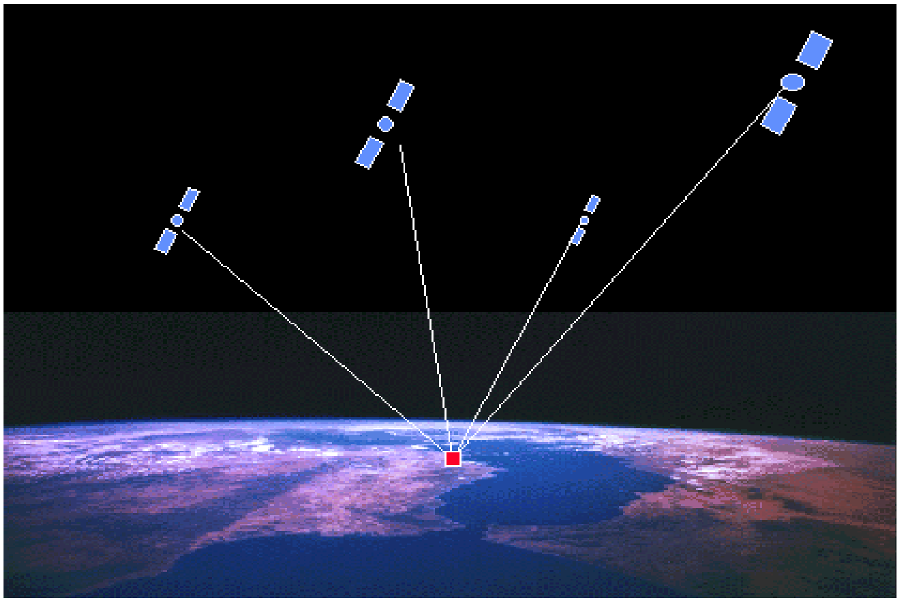

Figure 2. Four Satellites in View

GPS receivers collect signals from satellites in view. They display a user's position, velocity, and time, as may be needed, for marine, terrestrial, or aeronautical applications. Some receiver units display additional data, such as distance and bearing to selected waypoints or digital charts.

2.4 What is DGPS?

To overcome the measurement error inserted by SA into the standard positioning service signal, the receipt of a differential corrections signal can be introduced into a GPS receiver. This type of augmentation is generally referred to as a Differential Global Positioning System (DGPS). Depending on the correction method utilized, DGPS can provide an accuracy of from eight meters to better than one meter

2.4.1 How DGPS Works

DGPS is based upon knowledge of a highly accurate, geodetically surveyed location of a GPS reference station. This reference station observes GPS signals in real-time and compares their ranging information to the ranges expected to be observed at its fixed point. The differences between observed ranges and predicted ranges are used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed positions – See Figure 3.

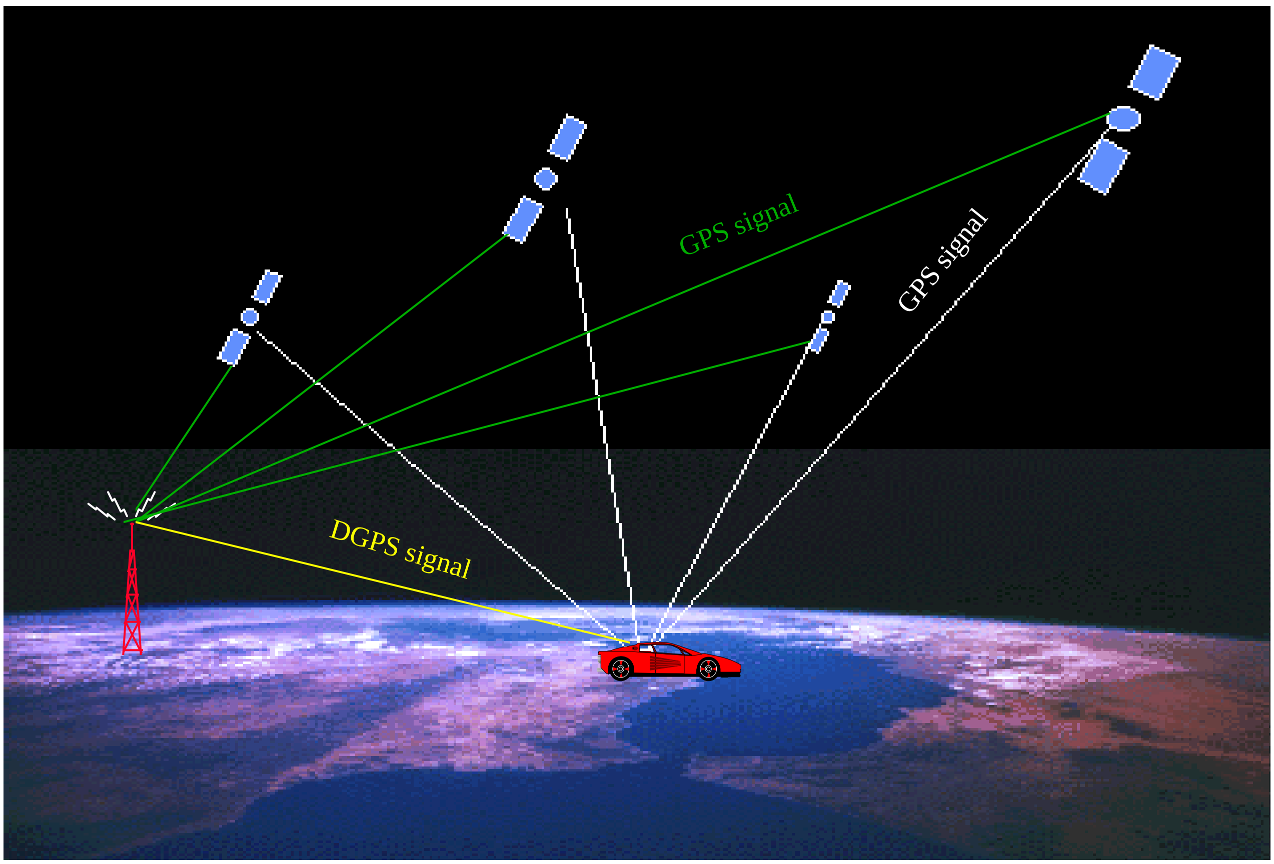

Figure 3. DGPS Principle of Operation

There are several methods to broadcast a differential correction signal from a reference station to users. These are:

- Geostationary satellite link
- Commercial FM subcarrier
- Radiobeacon

Of the three methods, two are the most prevalent: Radiobeacon. which is utilized extensively by the U.S. Coast Guard/Army Corps of Engineers, and geostationary satellite link which is utilized by a commercial service provider and will be the technology utilized by the FAA for its Wide Area Augmentation Service (WAAS).

Although, from a technical perspective, commercial FM subcarrier is feasible to provide correction signals, it has limited viability for a ubiquitous national service due to its limited range and the fundamental lack of available commercial radio stations in many areas of the country – especially in Alaska. Moreover, even among those commercial stations that are actively broadcasting, many stations may not make their subcarrier available for DGPS service due to its use for more lucrative business applications.

2.5 National Augmentation Development

In response to the Joint Task force report recommendations, the Department of Transportation began the process intended to reduce the number of Federal augmentation systems fielded while meeting the needs of Federal land, marine, and aviation users. The effort is being conducted in three phases. The first determined what systems would best meet Federal user requirements, the second determined the technical feasibility of this approach, and the third will culminate with an implementation policy based on the recommendations from the first phase.

The first phase evaluated the capabilities of many augmented GPS systems to determine the optimum integrated mix of systems to meet the navigation and positioning requirements of all Federal land, marine, and aviation users. The process compared public, private, national, and international augmentation systems with Federal land, marine, and aviation requirements. The analysis determined that no single system could meet user requirements for all applications. The recommendation, published in December 1994, presented an approach that would meet most user requirements, including many non-Federal civilian users. The final recommendations were:[4]

- Expand for use in surface applications a US Coast Guard like system to cover those sections of the country not currently covered by the US Coast Guard,

- Require all reference stations to comply with the Continuously Operating Reference Station (CORS) standard for post processing applications, and

- Implement the FAA's Wide Area Augmentation System (WAAS) for en-route through Category I landings and the Local Area Augmentation System (LAAS) for Category II and III landings.

The GAO study and the Augmentation Study reached similar conclusions concerning using a single DGPS system to meet all user requirements. In the past, systems were developed to meet the "type of application and geographic coverage" specific users required, limiting their ability to meet other users

[4] A Technical Report to the Secretary of Transportation On A National Approach to Augmented GPS Services" in December 1994.

requirements.[5] This concept led to the recommendations above for a set of systems that together would be the optimum integrated system to provide GPS augmentation services nationwide.

The recommendation to expand the Coast Guard system needed additional analysis (spectrum availability, number of reference stations, etc.) to ensure the expansion was technically feasible. This was Phase Two of the effort and required about 18 months to complete. Sufficient system design has now been completed that demonstrates the feasibility of the Nationwide DGPS system to cover the remaining 55% of the contiguous US and parts of Alaska not currently covered by the USCG system (Hawaii and some US territories [e.g., Puerto Rico] are currently covered). Additionally, several technical and administrative hurdles have been overcome including acceptance by the National Telecommunication and Information Administration (NTIA) of a footnote in the frequency allocation table to allow land use of a portion of the maritime frequency spectrum for this function.

The third and final study phase has been undertaken by Federal Highway Administration (FHWA), under the direction of the Office of the Secretary of Transportation (OST). This phase is a study to consider the institutional issues associated with the development of a policy for the implementation of such a service. This policy development considers several important aspects of the Federal government's role in establishing such a service including:

- The public safety benefits
- Cost savings for government users
- The potential for an improved quality of life for the general population

This is the subject of the remainder of this report.

3. OUTLINE OF PRESIDENTIAL DECISION DIRECTIVE, NSTC-6

The Presidential Decision Directive (PDD) of March 28, 1996 gave further direction to Federal agencies, which needed to be considered before the Nationwide DGPS service could be implemented. The President's goals detailed in the PDD are:

- Strengthen and maintain our national security
- Encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide
- Encourage private sector investment in and use of US GPS technologies and services
- Promote safety and efficiency in transportation and other fields
- Promote international cooperation in using GPS for peaceful purposes
- Advance US scientific and technical capabilities

[5]Global Positioning Technology, Opportunities for Greater Federal Agency Joint Development and Use, GAO/RCED-94-280, General Accounting Office, September 1994, page 5.

The President directed the Department of Transportation to:

- Serve as the lead agency within the US Government for all Federal civil GPS matters.
- Develop and implement US Government augmentations to the basic GPS for transportation applications.

In cooperation with the Departments of Commerce, Defense and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and US Government augmentations as standards in domestic and international transportation systems.

In cooperation with other departments and agencies, coordinate US Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.

Finally, one of the seven policy goals set forth in the PDD that is critical to this effort is:

"To the fullest extent feasible, we will purchase commercially available GPS products and services that meet US Government requirements and will not conduct activities that preclude or deter commercial GPS activities, except for national security or public safety reasons."

4. REQUIREMENTS

4.1 Revalidation of User Requirements from 1994 Augmentation Study

The first step in this effort has been to revalidate the user requirements collected for the 1994 Augmentation study which indicated a need for a Nationwide DGPS service and identified public safety requirements. The revalidation has been completed and results are substantially the same as in 1994. The most significant difference has been an increase in the number of applications that require real-time DGPS and the maturity of these applications. The applications still fall within the general categories from the 1994 Augmentation study, but the specific applications have expanded. New applications generally fall within the realm of natural resource monitoring, infrastructure management, and navigation to specific points for additional data collection or specific infrastructure assets. Additionally, many of the applications are public safety related. In most cases, it is required that systems be compatible nationwide to facilitate interoperability and to minimize the number of different equipment packages.

4.1.1 Public Safety Requirements

Under the Presidential Decision Directive, the Federal government is required to purchase commercially available GPS products and services that meet US Government requirements and not conduct activities that preclude or deter commercial GPS activities, except for national security and public safety reasons. After an exhaustive search of Federal and state statutes, it was concluded that there is no codified definition of "public safety" or "safety of life". The DGPS Implementation Team developed the following definition for public safety which is based upon a definition presented by the Public Safety Wireless Advisory Committee (PSWAC) to the FCC. PSWAC was an ad hoc study group established by the Federal Communications Commission (FCC): and the National Telecommunications and Information Administration of the Department of Commerce. The original definition appears in a report submitted to the FCC and NTIA on September 11, 1996. "Public Safety" as used in this report is defined as:

"The public's right, as prescribed by law and exercised through Federal, state, or local government, or exercised through private entities that provide critical safety functions, to protect and preserve life, property, natural resources, and to serve the public welfare."

Public Safety needs for DGPS are defined as those uses by an organization that require a specified level of coverage, accuracy, availability, or integrity to perform their functions. Several Federal departments, agencies, and bureaus currently rely on DGPS for public safety applications. Federal agencies that are currently using DGPS include the US Coast Guard, the US Army Corps of Engineers, and the US Forest Service. Many other Federal agencies have requirements or are in the process of defining requirements for DGPS. Appendix B2 lists these agencies, their applications and accuracy requirements.

The railroads are an excellent example of an industry that will use DGPS to enhance public safety. The implementation of an anti-collision or "Positive Train Separation" (PTS) system requires a navigation service that provides nationwide coverage of the railroad track bed, which is available 99.9% of the time, provides a location accuracy of 10 meters, and an integrity alarm time of better than 10 seconds.

Other public safety requirements exist as well. Currently, the EPA is using DGPS (where an USCG DGPS signal is available) to monitor hazardous waste sites and water contamination. Monitoring water contamination requires collecting samples from various sites. As a function of this process, it is important that personnel return to the same location for future samples. Samples are compared over time to develop contamination trend data and plans for corrective action.

A similar function is also performed in agriculture to minimize the amount of fertilizers and pesticides that are used, thus limiting the adverse effects on the environment and the public. In both of these cases, the ability to monitor specific sites to develop trend data improves the ability of organizations to identify and correct potential public and environmental health hazards before they become critical safety threats. Real-time navigation back to these sites is critical to ensure both the accuracy of the data and to minimize the time spent locating points, many of which cannot be marked in any way.

Other examples of DGPS usage in Public Safety include locating fire hydrants and other public safety based infrastructure. In many cases, this infrastructure is located where it is not readily apparent in order to minimize damage due to vandalism. In other cases, this infrastructure can become buried under snow and ice that is cleared from highways. One example of this occurred in Pierre, South Dakota in the winter of 1996. Firefighters were unable to locate a fire hydrant buried in the snow drift to fight a fire in a warehouse. Fortunately no lives were lost, but the building and its contents (antique cars) were destroyed. Knowing accurately the location of fire hydrants and having the ability to quickly find them enables fire fighters to speed up their rescue operation, thus saving lives and property.

Additional public safety applications can be characterized as personnel safety. The United States Postal Service (USPS) is concerned with tracking personnel in high crime areas or where it feels mail carriers are at risk. Locating a mail carrier quickly and precisely during a robbery will reduce the potential for injury or even death. Many law enforcement applications exist. These include tracking officers in urban areas to provide backup when needed. Other law enforcement applications include tracking vehicles and containers to apprehend criminals.

Finally, the applications for Search and Rescue (SAR) were highlighted by many Federal, state, and local government organizations. One specific application from Minnesota that exemplifies the problem is determining where searchers have already looked. The logging roads in Minnesota can be very close to each other, sometimes separated by only a small creek or stream. It is difficult to distinguish which side has been searched and which hasn't. Searchers, often operating with limited information, may cover an area several times before they have assured themselves it was covered. This type of search wastes time and resources that could be used far more efficiently. Federal organizations that have SAR responsibilities, outside of law enforcement, include the US Forest Service and the National Park Service. They are often assisted by volunteer organizations such as the Amateur Radio Service, the Civil Air Patrol, and the US Coast Guard Auxiliary. Many organizations see the need for a single Nationwide DGPS service that provides a 10-meter accuracy and serves both rugged terrain and heavily forested areas as well as open land and urban areas.

Based upon recent interviews, the following list is a sample of Federal agencies, that have public safety requirements:

- National Transportation Safety Board (NTSB)
- US Environmental Protection Agency (EPA)
- US Department of the Interior (DOI)
- National Park Service (NPS)
- US Department of Energy (DOE)
- US Postal Service (USPS)
- US Department of Transportation (USDOT)
- Federal Railroad Administration (FRA)
- Federal Transit Authority (FTA)
- Federal Highway Administration (FHWA)
- United States Coast Guard (USCG)
- US Department of Agriculture (DOA)
- US Forest Service
- Natural Resources Conservation Service (NRCS)
- US Department of Justice (DOJ)
- Federal Bureau of Investigation (FBI)
- Drug Enforcement Agency (DEA)
- Immigration and Naturalization Service (INS)
- Department of the Treasury (DOTres.)
- Bureau of Alcohol, Tobacco and Firearms (ATF)
- US Department of Commerce (DOC)
- National Geodetic Survey (NGS)
- US Army Corps of Engineers (ACOE)
- Federal Emergency Management Agency (FEMA)

It should be noted that currently, absent the availability of a national DGPS system, a number of Federal agencies have been authorized access to the classified PPS devices to perform certain mission functions. The provision of a nationwide DGPS service with the characteristics of those contained in the USCG system would reduce the need to obtain these PPS devices.

The following table summarizes Federal requirements for coverage, accuracy, availability and integrity.

Table 1. Summary of Federal Agency Requirements

Department	Agency See Appendix A - Acronyms List	Usage	Coverage Area	Accuracy (meters)	Availability (%)	Integrity (seconds)
EPA	Nevada Division	Surveying	Nationwide	1-2	99.70	N/A
		Positioning	Nationwide	2 to 5	99.00	
		Navigation	Nationwide	1	99.70	
Department of Agriculture	USFS	Navigation	Nationwide	2 to 10	99.90	N/A
		Positioning	Nationwide	2 to 10	99.90	N/A
	NRCS	Navigation	Nationwide	1 to 10	99.90	N/A
		Positioning	Nationwide	1 to 10	99.00	N/A
Department of Energy		Tracking				N/A
		Positioning				
Department of Treasury	ATF	Tracking	Nationwide		>99.00	N/A
		Positioning	Nationwide		>99.00	
		Navigation				
Department of Justice	DEA	Tracking	Nationwide		>99.00	N/A
		Positioning	Nationwide		>99.00	
		Navigation	Nationwide			
	FBI	Tracking	Nationwide		99.90	N/A
		Positioning	Nationwide		99.90	
		Navigation				
Department of Interior	BIA, BLM, BOR, FWS, MMS, NPS, OSM, USGS	Surveying, Mapping, Positioning, Navigation	Nationwide	<1-5	99.90	20-120
Department of Transportation	FRA	Positioning	Nationwide	<5	99.90	<10
		Tracking	Nationwide	<10	99.90	<10
		Navigation	Nationwide	<10	99.90	<10
	FHWA	Positioning	Nationwide	1-5	99.70	<10
		Tracking				
		Navigation				
	FTA	Positioning	Nationwide	<5	99.90	<10
		Tracking	Nationwide	<5	99.90	<10
		Navigation	Nationwide	<10	99.90	<10
	USCG	Positioning	Waterways	<3	99.90	<10
		Tracking	Waterways	<10	99.90	<10
		Navigation	Waterways	<10	99.90	<10

Table 1. Summary of Federal Agency Requirements (continued)

Department	Agency	Usage	Coverage Area	Accuracy (meters)	Availability (%)	Integrity (seconds)
Independent Agencies						
United States Postal Service		Tracking	Nationwide	<5	99.70	<10
		Positioning	Nationwide	<5	99.70	<10
		Navigation	Nationwide	<5	99.70	<10
National Aeronautics and Space Administration	Jet Propulsion Laboratory	Tracking	Nationwide			
		Positioning				
		Navigation				
Smithsonian	GIS Laboratory	Tracking		1		
Federal Emergency Management Agency		Navigation	Nationwide	<10		
		Positioning	Nationwide	<10		

4.1.2 Navigation and Positioning Requirements for Public Safety Applications

The previous sections have provided background on public safety applications. What has been more difficult to quantify is the coverage, accuracy, availability, and integrity requirements for navigation and positioning. Each of these parameters is important. If any parameter is not met, the users' requirements cannot be met.

Users often referred to their coverage requirement on a case by case basis. In most applications, coverage is based on a specific incident, point, or set of points that need to be found or, once found, returned (or navigated) to. Many of these applications are time critical and there is insufficient time to establish infrastructure to support them. In other cases, it is possible, although time consuming and expensive, to post process data. Several examples of nationwide surface requirements exist for law enforcement and personnel safety. When the SAR applications are examined as a whole, it is clear that substantial public safety benefits for a nationwide service exist.

Some augmentation systems use frequency spectrum where DGPS signals are line-of-sight originating from either space based or ground based transmitters. These systems will not meet the requirement to provide signals in areas where natural or man-made obstructions (e.g., buildings, trees, and mountains) exist. Moreover, these services generally do not conform to any recognized national and/or international standards for this type of service.

Users were most familiar with their accuracy requirement and were able to characterize their requirements very well. As illustrated in Table 1. above, most users with public safety applications had accuracy requirements on the order of 1 to 10 meters.[6] Others had accuracy requirements greater than this and rely

[6] This accuracy is comprised of both static positioning and moving (or navigation) requirements. Understanding this distinction is important since measurements taken in a static mode can be averaged or statistically sampled over a period of time and an accurate measurement determined; whereas navigation accuracy is achieved on a moving platform and measurements must be made instantaneously.

to a great extent on either post processing data or establishing a reference station for a short period of time to perform their required function.

For system availability,[7] the most stringent user requirements come from the railroad industry and law enforcement. These groups need the system to be operational and useable for navigation or positioning 99.9% of the time. This equates to less than 1/2 day (8.8 hours) of outage over a one-year period.

In the case of integrity,[8] the most stringent user requirements come from the railroad industry, law enforcement, and natural resource monitoring users. These groups need to know, as soon as possible, when the system may be unreliable. When integrity requirements were reviewed starting at 10 minutes and going through 1 second, most users fell within the range of 10 seconds to 20 seconds, with the navigation requirement of 10 seconds and the natural resource monitoring having the 20-second requirement.

5. THE PRESIDENTIAL DECISION DIRECTIVE, NSTC-6

The PDD is the basis and the guide for GPS and its augmentations.

5.1 Goals

As identified previously, there are several fundamental goals that the President put forth. Each of these is listed here within the context of expanding the USCG DGPS system to a Nationwide DGPS system.

5.1.1 Strengthen and maintain our national security

The PDD states that the National Command Authority will maintain control over all GPS Augmentations. In the event that the President declares a national emergency and limits the availability of GPS and its augmentations, the Nationwide DGPS system will operate in an emergency mode that denies its service to hostile forces.

5.1.2 Encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide

The USCG DGPS service has been accepted as an international standard by many countries. The current International Association of Lighthouse Authorities (IALA) list shows 22 countries actively operating or planning systems that are compliant with ITU-R M.823. In addition to the Federal agencies that are developing their own unique augmentation systems, many more see benefits from a nationwide service but do not have the resources to see their needs met. These agencies include many of the health services that track diseases or offer assistance in remote areas of the country. Other uses include monitoring wildlife to determine environmental health and monitoring contamination sites. In the words of industry officials referring to the LF/MF radiobeacon system, “As an autonomous unit, accuracy is critical to meeting the needs of users.”[9] These examples indicate how widespread the acceptance of GPS will be when the greater accuracy, availability, integrity, and coverage are available to users.

[7] Availability is defined as the percentage of time that navigational signals transmitted from external sources are available for use.

[8] Integrity is defined as the ability of a system to provide timely warnings to users when the system should not be used for navigation

[9] National Research Council Symposium, International Issues of the Global Positioning System, March 26, 27, 1997.

5.1.3 Encourage private sector investment in and use of US GPS technologies and services

Perhaps the single most significant barrier to widespread use of GPS and its associated technologies is the accuracy currently available. In the words of industry officials, "Accuracy of the current systems is a constraint. It needs to be on the order of a few meters."[10] If this constraint can be overcome, private sector use and investment in GPS technology will quickly spread.

5.1.4 Promote safety and efficiency in transportation and other fields

As just one example, the Federal Railroad Administration (FRA), in their report to Congress in 1995[11] on Positive Train Separation (PTS), stated that without the Nationwide DGPS service, PTS is unlikely to occur. The NTSB has identified implementation of PTS as one of its highest priority safety goals.[12] Additionally, it has been conjectured that with seamless coverage of the CONUS, PTS will allow the railroad industry to increase the freight capacity of the existing rail infrastructure by 25-30%.[13] This is an example of just one segment of the transportation industry. Increases in safety and efficiency have been noted in the marine transportation sector as well.[14] Finally, the Virginia Department of Transportation (VDOT) sponsored a study to examine methods of collecting Highway Inventory Data with GPS and found that the Standard Positioning Service (SPS) did not have sufficient accuracy to support the varied applications they examined. The report also concluded that "differential GPS is a viable method for VDOT to use to collect spatially related data and the attributes to be used in a GIS."[15]

5.1.5 Promote international cooperation in using GPS for peaceful purposes

Discussions with Canadian officials have shown them to be very interested in such a system as well. The Canadian Coast Guard has already installed 16 beacons and has plans for 4 more. During discussions in 1996, Transport Canada officials were very positive about implementing such a system for surface applications, especially north of the major population centers, where there are large tracts of wilderness and where both communication and other infrastructure are scarce. Other countries also see the benefits of this system to meet their public safety requirements. The United Kingdom, in a recent press release, will implement a radiobeacon DGPS system for marine applications.[16] IALA lists 22 countries that either have plans to implement or have already implemented this system in order to ensure a seamless marine radionavigation service worldwide.

5.1.6 Advance US scientific and technical capabilities

One of the most significant benefits of having a 1 to 10 meter grid that covers the surface of the US is the ability to map locations and then to associate information with that data. It will aid in generating a "sense of space." The information revolution has just begun. The opportunities that the information revolution, coupled with a real-time spatial reference system present, an immense opportunity for increasing our understanding of our surroundings and has only begun to be fathomed. Examples of this abound. One

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[10] National Research Council Symposium, International Issues of the Global Positioning System, March 26, 27, 1997.

[11] Differential GPS: An Aid to Positive Train Control, Report to the committees on Appropriates, Federal Railroad Administration, June 1995, page ii.

[12] Comments by Jim Hall, Chairman, National Transportation Safety Board, at the opening of public hearings held in June, 1996 regarding the Silver Spring, Maryland train accident in February, 1996.

[13] This is a commonly held assumption within the Rail Industry.

[14] The US Coast Guard has documented a 66% reduction in the time required over traditional method to set buoys.

[15] Case Studies in Collecting Highway Inventory Data with the Global Positioning System, Virginia Transportation Research Council, May, 1996.

[16] UK Press Release, March 18, 1997.

specific example is using DGPS to monitor and remove radioactive contamination from the Hanford Nuclear Facility in Washington.[17] Another example is the use of GPS for completing a comprehensive road inventory as a foundation for computer generated road mapping.[18] The state of Texas has also identified many applications that would be enhanced by having a 1 to 10 meter grid across the US.[19]

5.2 Department of Transportation Responsibilities

The President assigned several responsibilities to the Department of Transportation through the PDD. Each of these responsibilities is detailed below along with the implications of implementing the Nationwide DGPS service.

- Serve as the lead agency within the US Government for all Federal civil GPS matters

USDOT has coordinated this approach with many agencies within the Federal government as well as many state and local governments. The USDOT has been in many cases the catalyst for bringing diverse groups together and sharing their ideas. During the development of this report and the previous studies, it has been a primary focus to include all applications not only within the fields of transportation but many other fields as well. In this respect, USDOT earned its responsibility as lead agency within the US government. The principal criticism we have heard is that potential users are frustrated over USDOT's seeming inability to implement a Nationwide DGPS service. They see the Nationwide DGPS service as fundamental to a national approach to augmented GPS services, which is needed to achieve their public safety missions.

- Develop and implement US Government augmentations to the basic GPS for transportation applications

The GAO study, the Augmentation Study, and now this study have identified the benefits of implementing the minimum number of augmentation systems for transportation and other applications. Implementing the Nationwide DGPS Service will support this requirement. It will enhance the public safety benefits of surface transportation. Additionally, it will enhance the public safety benefits of many other Federal, state, and local government organizations.

- In cooperation with the Departments of Commerce, Defense and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and US Government augmentations as standards in domestic and international transportation systems

The USCG DGPS service has become a standard internationally (RTCM SC-104 and ITU-R M.823). By increasing its coverage in the US to cover the remaining 45% of the contiguous US, many more applications will become viable. This will further promote commercial applications of GPS technologies and acceptance of the Nationwide DGPS Service as a standard both domestically and internationally. Additionally, these new applications represent a demand that has not materialized due to the unavailability of a nationwide service.

- In cooperation with other departments and agencies, coordinate US Government-provided GPS civil augmentation systems to minimize cost and duplication of effort

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[17] Rad Rover: GPS Visits the Hot Spots, GPS World, May 1994

[18] Letter from the South Dakota Department of Transportation, Office of the Secretary to Donald F. Kamnikar, Division Administrator, Federal Highway Administration dated October 21, 1996.

[19] United Through a Common Geography, Statewide Geographic Information Systems Implementation Plan, Texas Geographic Information Systems Planning Council, December 1996.

In this study and several previous studies, the USDOT has coordinated with other Federal departments and agencies as well as state and local governments, to ensure that their requirements are incorporated into the analysis. Many have stated that they would forgo implementations they have planned or would not replace existing systems they have deployed if the Nationwide DGPS Service were implemented. This system meets their requirements for coverage, accuracy, availability, and integrity.

6. DEPLOYMENT OPTIONS FOR IMPLEMENTATION OF A NATIONWIDE DGPS SERVICE

6.1 Introduction

The current study effort in connection with the development of a policy and implementation plan for a nationwide DGPS service is intended to be a continuation of the recommendations provided in a report dated December, 1994, entitled "A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services." It is not intended to supplant the aforesaid 1994 study and research all possible alternatives for the provision of GPS augmentation service.

The 1994 report documented the development of recommendations for a national approach to augmented Global Positioning System (GPS) services. Study participants included the Institute for Telecommunication Sciences who led a team that included the U.S. Army Topographic Engineering Center, the Volpe National Transportation Systems Center, and Overlook Systems Technologies, Inc. The study team identified Federal navigation, positioning, and timing requirements for land, marine, air, and space modes of operation. The study team then evaluated numerous operating and proposed systems that augment the GPS Standard Positioning Service. The most promising systems were combined in six different architectures intended to meet the widest possible range of user requirements. One of these architectures was eliminated from consideration due to technical concerns. The study team evaluated each of the remaining architectures against a set of performance, cost, and security factors. Based on the architecture evaluations, the study team developed a set of recommendations for a coordinated, national approach to augmented GPS services that meets Federal requirements while avoiding unnecessary duplication of facilities. The recommendations are as follows:

- FAA should continue to implement its wide area augmentation system (WAAS) and local area DGPS systems as planned.

- USDOT, in coordination and cooperation with USDOC, should plan, install, operate, and maintain an expanded low frequency/medium frequency beacon system modeled after USCG's LADGPS system to provide nationwide coverage for land and marine users. Prior to implementing this system, a study should be performed to determine the number and optimum location of beacons necessary for nationwide coverage.

- All Federally provided reference stations should comply with the continuously operating reference station (CORS) standard.

- USDOT should continue to evaluate system risks and appropriate measures needed to ensure safe and reliable augmentation services. Further, USDOT, with the assistance of DOD, should test and evaluate measures to mitigate the susceptibility of federally provided augmentation systems to all forms of interference, including jamming and spoofing.

- USDOT, in conjunction with other Federal agencies, should coordinate the implementation, operation, and maintenance of all Federally operated augmented GPS systems to ensure optimal use of resources by maximizing commonality of system components.

- Different formats for augmentation data have been developed to meet the requirements of particular user communities and to make optimum use of data links planned for augmenting GPS. For the architectures considered, there is no compelling technical or economic reason for developing a single, standardized data format for use by all Federally-operated augmentation systems. Consequently, in the near term, effort should not be expended on the conversion of broadcast formats to a common data format. Use of the Receiver Independent Exchange (RINEX) format is recommended for post-processing applications. In addition, an international standards working group should be identified to address any future data format issues.

- A central repository for GPS augmentation information should be maintained. This information should be made available to the public via the existing USCG Navigation Information Service.

- A further study should be undertaken to investigate spectrum allocation and bandwidth requirements for any future, Federally provided, differential GPS system.

6.2 Nationwide DGPS Implementation Options

The 1994 Augmentation Study recommended four general solutions to meet users requirements. These included:

- The Continuously Operating Reference Station (CORS) for applications that need very high precision but not in real-time

- Implementation of the FAA proposed Local Area Augmentation System (LAAS), which uses pseudolites and a VHF data link in and around airports

- Implementation of the FAA proposed Wide Area Augmentation System (WAAS), which uses a downlink on L1 frequency from geostationary satellites

- Expanding the LF/MF DGPS system the US Coast Guard and US Army Corps of Engineers has developed and implemented on the coasts and inland waterways

Each of these systems has been developed to meet specific requirements for particular users. The requirements that are of interest in this report are for surface users with applications that require real-time position and navigation for public safety on the order of 1 to 10 meters, with an availability of 99.9%, an integrity of better than 10 seconds, and coverage on the surface of the earth.

6.2.1 CORS

Comparing these requirements to the above systems, two can be discounted immediately. First, the CORS system, while providing very high accuracy, does not provide this in real-time. Thus, this system will not meet the real-time requirements of the public safety applications.

6.2.2 LAAS

Second, the FAA's LAAS will be located near or on airports and will use a VHF data link for broadcasting the differential corrections and L1 for the broadcast of additional ranging signals. The VHF data link will have a range of 20-30 miles around major airports where category I, II, and III landings will occur while the L1 signal from the pseudolites[20] has a shorter range due to the frequency and the dynamic range of the GPS receiver on the aircraft.

6.2.3 WAAS

As stated previously, the FAA's WAAS uses a downlink from geostationary satellites in the L1 frequency band. L1 is a line-of-sight communication link that can suffer severe attenuation whenever there is an object between a receiving antenna and the satellite. This is significant for surface applications since this signal will not penetrate mountains, buildings, and other surface structures. Additionally, a geostationary[21] satellite, as the name implies, is in a fixed location relative to the earth's surface. As an example of the impact this elevation angle may have, consider the coverage of the Columbia River Gorge from the Pacific coast to Idaho along the Washington/Oregon state line. This area contains two major east-west railroad routes, an interstate highway, large areas of US Forest Service land, and numerous national parks. The elevation angle of a geostationary satellite located directly south of this point will be approximately 25 degrees. Obstructions of this height above the horizon will block the communication link from the satellite to the user receiver. For the Columbia River Gorge, the primary blockage will be terrain.

6.2.4 Nationwide DGPS Service

The Nationwide DGPS Service will use a low/medium frequency communication link. This has the advantage of not being affected by terrain to a significant extent. It relies on a ground wave propagation path to convey the information to users. Based on data collected by the Institute for Telecommunication Sciences (ITS) of the National Telecommunications and Information Administration (NTIA) of the Department of Commerce (DOC) using radiobeacons in various parts of the country, a propagation model was developed and validated for the USCG Radiobeacon service. This model used terrain data as well as ground conductivity to determine ground wave coverage and also considered sky wave propagation to minimize any potential for interference between LF/MF Radiobeacon sites. This model was used to verify current coverage of the USCG/ACOE DGPS service and to estimate the number of additional sites that would be necessary to provide full redundant coverage of the contiguous US and Alaska (As noted previously, there is already coverage in Puerto Rico and Hawaii.). Based on the data collected, terrain blockage plays a relatively minor role in propagation properties at these frequencies. The significant factor in propagation at this frequency is ground conductivity. This is a fairly well established parameter and easily modeled. The Federal Communication Commission (FCC) has used this parameter to establish frequency allocation tables for various Low Frequency (LF) and Medium Frequency (MF) users nationwide. The report from ITS/NTIA suggests that to cover the remaining portion of the 48 contiguous states with a redundant coverage would take an additional 54 radiobeacon sites.[22] This would meet all the requirements for identified public safety applications by providing nationwide surface coverage, providing a 1 to 10 meter accuracy, providing 99.9% availability, and providing a better than 10 second integrity.

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[20] Pseudolites are equipment that provide a short range broadcast of a GPS like signal from selected terrestrial locations.

[21] Geostationary - designating a satellite in an orbit above the equator, revolving at a rate of speed equal with that of the earth's rotation so as, in effect, to be hovering over a point on the earth's surface.

[22] Coverage for Alaska has been examined and approximately 12 additional sites will be required. Physical constraints such as availability of electrical power, access for routine maintenance, etc. are being examined to determine the most cost effective distribution of sites to ensure coverage and limit maintenance and infrastructure costs. It is clear that certain corridors such as railways, highways, and pipelines will allow easy access to the appropriate infrastructure. Large sections of the interior of Alaska must be examined closely for appropriate infrastructure to support a LF/MF Radiobeacon site. Additionally, there may be limited coverage of the northern portion of Alaska due to signal availability from the satellites. Future analysis will be conducted to determine coverage constraints in this region.

6.2.5 System Versus Requirements

Table 2 below compares user requirements to system capability. As illustrated in the chart, the only system that is fully capable of meeting nationwide, surface user, public safety requirements is the LF/MF Radiobeacon DGPS system.

Table 2. User Requirements and System Capability

System	Complete Surface Coverage	Accuracy	Availability	Integrity	Real Time
CORS	Yes	Yes	NA	NA	No
LAAS	No	Yes	Yes	Yes	Yes
WAAS	No	Yes	Yes	Yes	Yes
LF/MF Radiobeacon	Yes	Yes	Yes	Yes	Yes

6.2.6 LF/MF Radiobeacon Current Status

The US Coast Guard (USCG) and US Army Corps of Engineers (ACOE) have implemented and are currently supporting a DGPS service to provide a signal designed to provide maritime navigation safety on the nation's coasts and other navigable waterways. The coastal portion of the DGPS service is almost complete and the river portion is being expanded. Based upon computer simulation modeling conducted by the Institute for Telecommunication Sciences (ITS) of National Telecommunications and Information Administration (NTIA), it is estimated that the USCG and ACOE DGPS systems furnish a DGPS service to approximately 55% of the US land mass and 65% of its population. This coverage is illustrated in Figure 4 below.

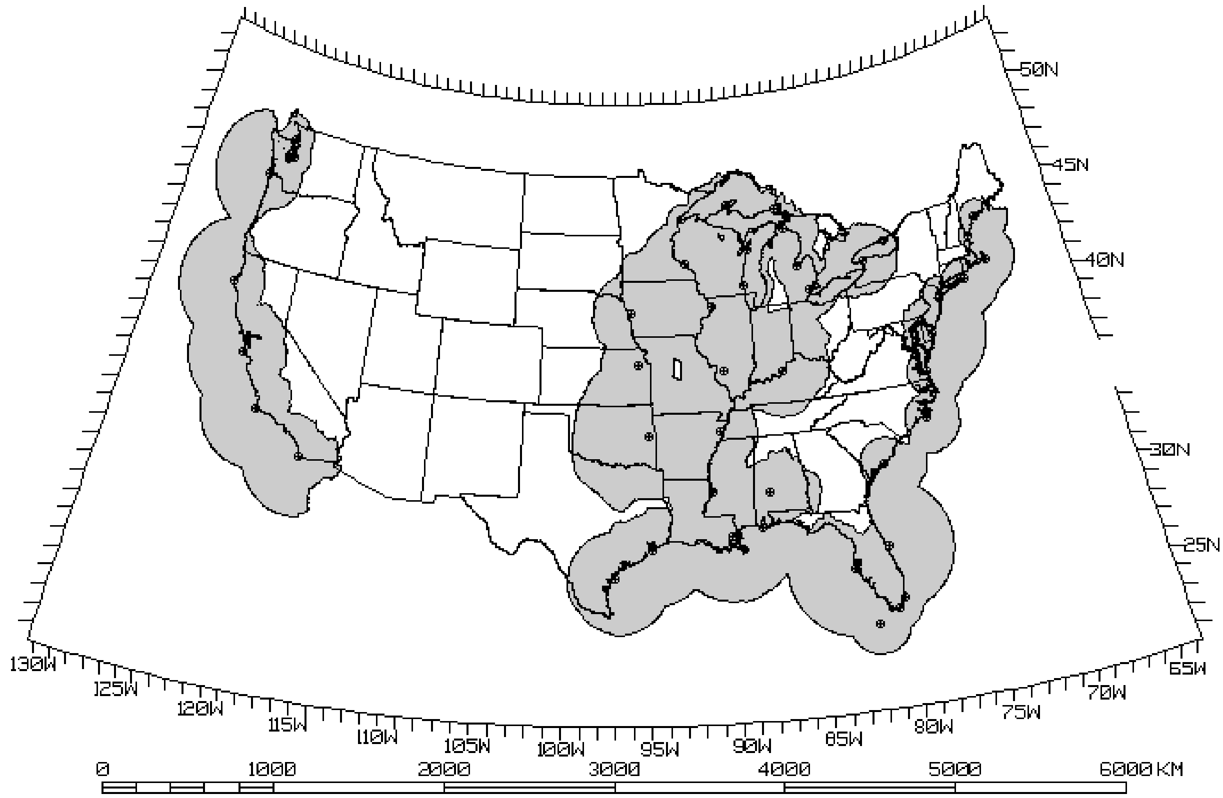

Figure 4. Existing coverage of USCG/ACOE DGPS Service

The following paragraphs address key issues related to the possible roles of the public and private sector in the expansion of the DGPS service. Inasmuch as the service expansion would be conducted in the interest of public safety, it is important to note that throughout the investigation of the various service implementation options, there was a presumption that the service is to be offered as a full and open service and the signal will be available at no cost to the end user. This presumption was validated when the President signed into law, on October 27, 1997, the Department of Transportation's fiscal year 1998 appropriation bill that became part of Public Law 105-66. Section 346 (c)(2) of the law states " ensure that the service of the NDGPS is provided without the assessment of any user fees; ..".

6.3 Private-Sector Implementation

One option for expanding the existing DGPS network is to rely on the private sector to implement it. From the viewpoint of the Federal government, this approach would be preferable because of the current lack of funding required to implement such an expansion and the cost to maintain the system after its installation. However, there are both threshold and organizational issues that make such an approach unlikely. Threshold issues include legal prohibitions, frequency concerns, and, perhaps most significantly, the uncertainty of a return on investment, and liability. Organizational issues include organizational form and tax liability concerns.

6.3.1 Threshold Issues Inhibiting Private-Sector Implementation

In this model, it is assumed that *no* public funding is provided, and there is only minimal public agency involvement. This model is unlikely for several threshold reasons. First, the United States Code (USC) restricts private provision of maritime navigational aids. Title 14 Section 83 of the USC [14 USC Sec. 83] states " No person, or public body, or instrumentality, excluding the armed services, shall establish, erect, or maintain any aid to maritime navigation ". Moreover, Title 33 Part 66 Subpart 66.01 Section 66.01-1 of the Code of Federal Regulations [33 CFR 66.01-1 (d)] states "with the exception of radar beacons (racons) and shore based radar stations, operation of electronic aids to navigation as private aids will not be authorized." Therefore, a coordinated DGPS would be severely hampered by pure privatization. Second, the USCG is not authorized to contract for operational integrity oversight with a private entity. Third, a private entity would not likely be able to obtain radio bandwidth from the FCC since the current USCG DGPS service uses an exclusive maritime frequency that no private entity has the authority to use. Fourth, and most importantly, without the ability to charge a fee for the signal, it is highly unlikely that private entities would be willing to spend significant amounts of money, and assume liability, to undertake DGPS in the hope of creating new markets, since their competitors would be "free-riders." Here again, Public Law 105-66 Section 346 (a) and (c) (2) clearly and explicitly states that the NDGPS Service will be provided by the Federal government without any user fee.

6.3.2 National Telecommunications and Information Administration (NTIA) Bandwidth

NTIA bandwidth would probably not be available to a radiobeacon site that is entirely privately owned and operated. NTIA bandwidth may possibly be made available for a hybrid public/private site, and would assuredly be available for a Federal sector DGPS radiobeacon broadcast.

In general, use by government or non-government users of certain bandwidths is governed by The Communications Act of 1934. The Act states that radio stations belonging to and operated by the United States will not be subject to FCC regulations and licensing requirements. The President will assign the frequencies for these radio stations.

Therefore, to benefit from the exemption from FCC procedures outlined in the Act a radio station must "belong to" and be "operated by" the United States.

There is no case law interpreting the phrase "belonging to and operated by the United States." Federal regulations provide that non-government stations may be authorized to use Government frequencies above 25 MHz if the FCC finds that such use is necessary for coordination of Government and non-Government activities, provided that, *among other things*, the operations conform to NTIA rules.

Fortunately, the NTIA's Manual of Regulations & Procedures for Federal Radio Frequency Management ("Manual") does provide some guidance. The Manual states that its guidelines "are to assist in the determination of whether or not a station belongs to and is operated by the United States...."

The factors listed are:

- The department or agency concerned should be able to exercise effective control over the radio equipment and its operation; and

- The department or agency concerned assumes responsibility for contractor compliance with Executive Branch, departmental, or agency instructions and limitations regarding use of the equipment and ensures that such instructions and limitations are met when operating under the authority of an Executive Branch frequency authorization to the department or agency; and

- The station should be operated by an employee of the department or agency or by a person who operates under the control of the department or agency on a contractual or cooperative agreement basis, and who is sufficiently under supervision of the department or agency to ensure that Executive Branch, departmental, or agency instructions and limitations are met.

Based on the Manual, it appears that so long as a Federal agency exercises "effective control" over the DGPS sites, NTIA bandwidth should be available to both a public/private arrangement, or a wholly public-sector operation. Both a purely private as well as a state government operation apparently would not be exempt from FCC licensing procedures and would not be entitled to a Federal government frequency, even if it is fulfilling a public service. Note, however, that the Manual does not describe the extent of Federal department or agency involvement that is required where a station is operated on a "contractual or cooperative agreement basis." Thus the required extent of Federal government involvement may be fairly minimal, provided that it is "sufficient to ensure that Executive Branch, departmental, or agency instructions and limitations are met."

In either case, civilian commercial usage of the frequencies currently used by the USCG DGPS would be a major concern to the USCG as stated by a USCG official of the Radionavigation Center on June 10, 1997. The main reason for this concern is signal integrity, interference, and the concomitant liability issues that could be raised because of it. The primary application of the USCG DGPS for its intended users is public safety, e.g., marine navigation. If a commercial DGPS signal is received by a primary user of the USCG DGPS and this signal has a lower integrity standard than the USCG standard, the USCG may be enjoined in a liability action and faced with continually proving no-fault. This potential for litigation would place the USCG in the untenable position of having to constantly monitor commercial signal providers and possibly initiate corrective actions. This would place an unwarranted additional burden on the USCG. The USCG addressed these concerns by denying any private entity the authority to operate electronic aides to navigation in the Code of Federal Regulations Title 33 Part 66 Subpart 66.01 Section 66.01-1 [33 CFR 66.01-1 (d)]. Also, Title 14 Section 83 of the USC [14 USC Sec. 83] gives the USCG the authority to do so.

6.3.3 Return on Investment

Full private-sector implementation of a nationwide DGPS network will require some form of return on investment (through usage, equipment fees, application fees, etc.) The initial capital investment required to complete a nationwide DGPS service coverage is sizable and the private sector would be expected to some how pass these costs along in order to recoup its investment. Currently, commercial DGPS service providers are using encrypted signals in proprietary systems.

Given a desire by the government for a full and open service and that the signal should be available at no cost to an end user as stated in Public Law 105-66 Section 346 (c) (2), how to obtain a return on investment becomes a major conundrum for the Private-sector Implementation model.

6.3.4 Liability

Liability issues create particular problems for full, private-sector implementation of a nationwide DGPS network. Private entities that would install, operate and maintain such a network would be potentially liable in a number of areas, as discussed below.

The manufacturer, designer, and distributor of unsafe products may be subject to potential tort liability under three legal theories: negligence, strict liability, and breach of warranty.

<u>Negligence</u> **-** Liability for negligence is predicated on a failure to exercise the appropriate level of due care to insure that a product or service does not subject the user to unreasonable risk. Duty of care is

commensurate with the risk of danger involved and requires a balancing of the likelihood of harm and gravity of possible harm against the burden of effective precautions. The balancing of interests renders the manufacturer or service provider liable for failure to prevent a foreseeable accident, but does not make them absolute insurers of the users of their products or services. For example, in the case of automobiles, courts generally do not require manufactures to design cars that are incapable of crashing or otherwise inflicting harm.

Manufacturers must exercise due care in designing a product or service, in selecting materials, in the production process, in performing reasonable tests and inspections, and in warning of any dangers. Moreover, one that utilizes component parts supplied by third parties has an obligation to conduct reasonable inspections and tests of those parts, and where appropriate, warn of possible dangers. Although manufacturers generally cannot rely on government inspections or tests, if the government tests a product, that can be evidence that the manufacturer exercised due care. The duty of all entities in the chain of distribution is to use a standard of care of a reasonably similarly situated entity. This is an interesting question in the context of DGPS, since the goal of the program is for a single unified broadcast of the signal. Thus, there would be no similarly situated entity against which the reasonableness of the actions of the entity transmitting the signal could be compared.

If it is determined that it is appropriate for a private entity to broadcast a signal, or for state or local governments to take responsibility for broadcasting signals in their respective jurisdictions, and appropriate legislative authority for such broadcast is either found in existing law or enacted, then the applicable standard of care could be heavily influenced by promulgation of Federal or state statutes or regulations. Tort law considers such statutes and regulations as admissible to show compliance (or lack thereof) with the required standard of care. Promulgation of Federal safety standards governing DGPS would diminish liability in some states where compliance with applicable laws or generally recognized standards provides a rebuttable presumption that a product is not defective or the defendant was not negligent.

Many jurisdictions permit plaintiffs to prove negligence by showing that the particular character or nature of the accident is such that it could only have been caused by the defendant's negligence. This method of providing liability applies where the defendant had exclusive control of the "product" at the time the negligent act occurred (rather than at the time of the accident), and there was no alteration or tampering with the product. Thus, in the context of automated highway systems dependent upon the DGPS signal, if the signal shut down causing a mass pile-up on the highway, plaintiffs might bring liability actions on the theory that the failure in the signal "speaks for itself."

Strict Liability - Rather than focusing on the conduct of the defendant, strict liability focuses on the defectiveness of the product. The rationale for this theory is the belief that manufacturers and sellers can best absorb the cost of defectively dangerous products because they can spread the cost of accidents among the many purchasers of their products. Because the defendant cannot absolve itself of liability based on due care, and no privity with the defendant is required, this strict liability has the potential to turn private enterprise away from participating in the DGPS.

Strict product liability does not apply to services, only to products. The dividing line is rather difficult to draw, and particularly difficult in the context of DGPS.

It is unclear from a review of case law to determine how DGPS might be viewed pursuant to case law. Public roads and guardrails and bridges associated with them generally are not considered to be products; they are services. For instance, in one case a father and his infant son sought compensation from a county for injuries sustained when their car hit a guardrail. The court upheld summary judgment in favor of the defendant on the grounds that the erection of a guardrail was a service rather than a product. On the other hand, one court held that a navigational chart utilized by airline pilots was a product rather than a service on the reasoning that since the defendant mass produced the charts without any individual tailoring, it undertook a special responsibility to insure that consumers would not be injured by the use of the charts.

While DGPS service contemplates facilitating the dissemination of information, the signal itself would be broadcast generally without any tailoring to specific users' needs. The determination of whether dissemination of the signal constitutes a product or a service will depend on the court's view of the information provided and the manner in which it is provided. It seems that the better argument is that the propagation of the DGPS signal would be more like the provision of public roads and guard rails than a navigational chart. Additionally, the public policy of spreading the cost among the many buyers of the dangerous product would not be met in the context of a "free" signal.

Assuming, for the sake of argument, that DGPS service is a "product," to establish strict liability, a plaintiff must prove that the product was defective. In a majority of states, the plaintiff must also show that the defect created an unreasonably dangerous condition that proximately caused the plaintiff's injury.

Some states do not consider a product unreasonably dangerous if the defect or risk is patent or openly obvious. In such cases, the plaintiff may be said to have assumed the risk. In the context of DGPS, the risk of failure of the signal appears obvious. However, the fact that the signal might be subject to failure may be less apparent to an unsophisticated user.

Product liability laws impose liability on manufacturers and sellers if the plaintiff was injured as a result of defects in design or manufacture. Design defects are problems with the design of the product itself, such as the failure to utilize adequate safety measures. Design defects include concealed hazards, failure to provide a reasonably safe device or mechanism, failure to utilize a safer design that was both feasible and available, and failure to use material that is suitable for its intended use. In the context of DGPS, safety could be designed into the system with multiple layers of redundancy, adequate testing procedures and posting of adequate warnings.

However, failure to warn does not seem to be a likely approach to tort claims for DGPS because it is difficult to fathom what warnings could possibly be expected when providing a free signal via radio broadcast.

Breach of Express Warranty - Express warranties are those promises, oral or written, made by the manufacturer or the seller of goods stating that the goods will conform to an affirmation or promise that became a part of the basis of the bargain. Thus it is unclear in the context of a free DGPS signal that a breach of express warranty theory would be available to injured parties. There is no payment or other consideration anticipated for the free propagation of the signal. Of all the potential theories of liability, breach of express warranty is the least likely to inhibit further deployment of DGPS.

Breach of Implied Warranty - This warranty covers the Buyer's reasonable expectation that goods purchased from a merchant will be free of significant defects and will perform in the way goods of that kind should perform. Again, the availability of this theory in the context of DGPS is questionable. Thus, whether this theory would be available in the context of DGPS may depend upon the jurisdiction in which the claim is brought.

6.3.5 Organizational Issues Inhibiting Private-Sector Implementation

In addition to the threshold issues raised above under liability, there are a number of organizational issues that may prohibit the private-sector implementation of this network. Organizational form and tax liability issues are primary barriers to private-sector implementation.

6.3.6 Organizational Form

To the extent that private-sector firms demonstrate interest in assisting with the deployment of a free radio-beacon augmented DGPS signal, either on an individualized basis or in association with a DGPS industry group, they will have to consider the type of legal entity that is most appropriate for their role. Consideration of the type of legal entity that best minimizes the potential of liability for system failures will most likely be the determining factor. Given the significant liability concerns raised above, a private entity that constructs and/or operates the portion of the DGPS system that provides navigation support for land oriented activities should be organized as a corporation. Simply stated, a corporation is an artificial person or legal entity created by or under the authority of state law. It ordinarily consists of an association of numerous individual "shareholders". A corporation is regarded in law as having a personality and existence distinct from that of its several members, and which is, by the same authority, vested with the capacity of continuous succession, irrespective of changes in its membership, either in perpetuity or for a limited term of years. The most distinguishing feature of corporations is that, except in circumstances where the corporation has no legitimate existence apart from its shareholders, individual shareholders are not personally liable for the debts of the corporation. It is principally for this reason that a corporation is the most likely form of organization for private participation in DGPS. It could be simply individual entities or a trade group donating funds, goods and/or services to the public sector for DGPS implementation, or a private entity or group of entities actually carrying out DGPS implementation.

Companies that are in the business of GPS goods and/or services could form a corporation for the purpose of promoting land-based DGPS. They might join in collaborative research on the architecture for land-based DGPS augmentation, or they might simply agree to donate funds and/or goods and services for the government's DGPS deployment. A corporate structure would insulate their personal assets from being at risk based upon liabilities incurred by the corporation, and would have the added advantage of providing the possibility of creating some tax advantages for participation.

A corporation may be either a for profit corporation or a tax exempt, non-profit corporation. Either of these modes of organization is available for participation of the private sector in DGPS.

6.3.7 Internal Revenue Code

The Internal Revenue Code (IRC) defines "tax exempt organizations" to include:

Corporations... organized and operated exclusively for... charitable, scientific, testing for public safety... or educational purposes... no part of the net earnings of which inures to the benefit of any private shareholder or individual, no substantial part of the activities of which is carrying on propaganda or otherwise attempting, to influence legislation (except as otherwise provided in subsection (h)), and that does not participate in or intervene in (including the publishing or distributing of statements), any political campaign on behalf of (or in opposition to) any candidate for public office.

Some aspects of the development of a land oriented DGPS system easily fall within the label scientific and thus qualify for tax exempt status. Others fall within the term "testing for public safety." However, these words do not clearly indicate that operating a system that provides or fosters public safety is within the scope of the Internal Revenue Code. Nevertheless, the term "charitable" has been interpreted very broadly and is not construed as limited to the other tax-exempt purposes specifically listed in the Code. As the Regulations point out, the term should be construed to include, among other things:

"Erection or maintenance of public buildings, monuments, or works; lessening of the burdens of government; and promotion of social welfare by organizations designed to accomplish the above purposes."

Organizations granted tax exempt status because they lessen the burden of government have included organizations that provide fire and rescue service for the general community or provide services in tandem with existing governmental agencies, such as assisting fire fighters, police and other personnel to perform their duties more efficiently during emergency conditions. Organizations that provide bus transportation to isolated areas of a community not served by existing city bus systems have qualified as tax exempt. In determining whether the activity of an organization lessens the burdens of government the Internal Revenue Service (IRS) will consider whether the organization's activities are activities that a governmental unit considers being its burdens, and whether the activities actually lessen the governmental burden. Thus, the fact that at least two government agencies (USCG and FAA) are currently (or soon will be) operating DGPS helps to define DGPS as a government burden. Additionally, if an agency such as FHWA had specific responsibility for land transportation oriented DGPS, the qualification of the purpose as one that lessens the burden of government would be strengthened. The IRS will consider the interrelationship between a governmental unit and the organization as evidence that the governmental unit considers the activity to be its burden. Thus, a private entity that provides DGPS enhancements to the USCG and FAA DGPS that further the mission of the USCG, FAA or FHWA clearly qualifies as a tax-exempt corporation under IRC Section 501(c)(3).

6.3.8 Tax Liability Issues

One way to fund the land transportation enhancements to DGPS through such a private corporation is to solicit contributions of funds or equipment from entities that have an interest in such development. Manufacturers of DGPS receivers may make such contributions to expand the market for their equipment or create new markets that will not exist unless the level of accuracy and reliability needed for land transportation applications is developed. Will funds or the value of equipment contributed to the tax-exempt entity to assist with the construction and operation of the system by manufacturers of DGPS equipment be deductible for Federal income tax purposes as charitable contributions?

Generally a tax deduction is allowed for a contribution to or for the use of any political subdivision of the United States for public purposes or to a corporation that is organized and operated exclusively for charitable, scientific or educational purposes. However, since the contributions in the context of DGPS would be related to development or expansion of the contributing entities' markets, the contributions may not be deductible. Somewhat analogous situations involve transfers of property to local governments. The IRS has determined and the courts have upheld denial of charitable deductions where the transfer enhanced the value of the donor's remaining property. At other times however, where the benefit realized by the donor is only incidental to the benefit received by the general public, the deduction has been allowed.

At this point in time, it is difficult to know what funds or equipment might be contributed to an entity developing a DGPS system or what indirect benefit might accrue to the contributing entity as a result of the existence or further development of DGPS. It seems likely however that substantial contributions would only be motivated by potential for significant indirect benefits. The only sure way to resolve the question of deductibility is to obtain an IRS ruling on the circumstance of each contributor. That approach is not useful for planning purposes.

Other potential downstream considerations make a tax-exempt entity questionable as the vehicle. No part of the net earnings of an organization that is tax exempt under the IRS may inure to the benefit of any private shareholder or individual. The entity may be able to license certain technologies developed in the course of development and installation of an expanded DGPS. Those license revenues will be more difficult to deal with because of the unrelated business taxable income rules applicable to tax exempt organizations; the prohibited transactions rules applicable to dealings between a private foundation and substantial contributors (if the entity is a private foundation) or the risk of loss of tax exempt status.

6.3.9 Public-Sector Implementation

At the other end of the spectrum is full public-sector implementation of a nationwide DGPS service. There are a number of arguments to support such an approach. Federal government agencies (the U.S. Coast Guard and Army Corps of Engineers) already operate DGPS systems that cover nearly 55% of CONUS. Such systems advance the mission and goals of the Department of Transportation and other Federal government agencies, and, as stated above, the private sector is likely to be unable or unwilling to provide the requisite service to meet important public welfare and economic needs. An opportunity to establish the additional sites relatively inexpensively is available. Also, the US Air Force (USAF) plans to decommission its Ground Wave Emergency Network (GWEN) late in FY 1998. This presents an excellent opportunity for both the USAF and the USDOT. The USAF saves the cost of decommissioning some of its GWEN sites while the USDOT saves the cost of acquiring real estate, environmental impact studies, and capital improvements. The USAF estimates it will cost about $250,000 to environmentally restore (putting it back to blackberry bushes and bunny trails) a GWEN site. Hence, it will cost the tax payers approximately $13 million to environmentally restore decommissioned GWEN sites. As a result, by reuse of GWEN sites and equipment, geographic coverage of the current USCG/ACOE DGPS service could be expanded in a very short time and the cost of providing an expanded DGPS service would be significantly reduced as well as the restoration cost avoidance associated with this reuse.

6.4 The Public Interest

Like the private sector, the public sector can also realize a wide range of benefits, life saving, cost savings and increased efficiencies from the deployment of a nationwide DGPS service. Hazardous waste management, law enforcement, emergency services and transportation activities are the primary areas where nationwide DGPS service can serve the public interest.

6.4.1 Organizational Issues Regarding Public-Sector Implementation

Traditional Federal Public Works Development, Funding and Operation **-** In the traditional model, Federal government agencies involved in implementing an expanded DGPS service would define the scope of the project, and undertake design and construction of the project either entirely with government personnel, as a sequence of competitively bid contracts, or as a turnkey design/build project. The project would be financed entirely with public funds. While the augmented GPS could certainly be deployed in this manner, this model may not be consistent with USDOT’s desire for private funding and speed in the process.

6.4.2 State Pooled Resources

In this model, the project would be funded either as a Federal/state partnership, or solely with state funds. This model presumes a very strong State interest. From a timing perspective, it has the disadvantage of requiring coordination of multiple jurisdictions with varying procurement laws, policies and political agendas, a lengthy process at best. If the implementation of DGPS service expansion is placed solely in States’ hands, it may have the added disadvantages of probably not qualifying for USCG oversight assistance, or for NTIA maritime frequency .

6.4.3 Liability Issues Regarding Public-Sector Implementation

The Federal Tort Claims Act (FTCA or Act) recognizes, subject to certain exceptions, the general principle that the United States should be liable for the negligence of Federal government employees and Federal and other agencies performing government functions when a private individual would be liable under similar circumstances. However, the Federal government’s liability is strictly limited by the Act. For instance, only actions for money damages are within the FTCA’s scope, not punitive damages. Also, strict liability is not available against the Federal government. Negligence must be shown even where the United States owns, manufactures, or designs the allegedly defective product.

The most important exemption of the FTCA is the discretionary function exemption. The purpose of this exemption is to immunize government employees from liability for formulating public policy. Courts examine whether the challenged conduct occurred in the course of making significant policy and political decisions.

The discretionary function exemption has been applied in a multitude of cases. Courts have held that the government's approval of designs and technology is within the discretionary function exemption. Also, governmental funding of activities and related involvement with parties receiving such funds, often will be within the discretionary function exemption. This is true even if the government supervises the activity or becomes involved in it. So long as the agency's actions further policy goals and are not specifically dictated by statute or regulation (or merely involve decisions resting on mathematical calculations), the discretionary function exemption will apply.

While the Federal government is not liable for merely inadequate warning, liability may attach if the government fails to issue any warning of a known hazard. For example, in one case the government was held liable for an air traffic controller's failure to issue a travel advisory because the air traffic controller's duty to issue the advisory was operational in nature, not discretionary. In the context of DGPS, one could argue that the decision to deploy the DGPS for national safety purposes is discretionary, and the manner in which the Federal government elects to deploy the system is not actionable. However, the day-to-day management of the system and dissemination of the signal arguably would be "operational."

In the event that the Federal government authorizes privatization of the DGPS service, it is questionable whether it would be liable under the FTCA in the event that its supervising evaluation negligently fails to cover a defect of the DGPS that has undergone an operational test and evaluation. It appears that the USDOT would have discretion to establish guidelines and requirements in the selection of "non-Federal entities" to perform DGPS service. The content of the guidelines would be subject to discretionary choices and judgments of USDOT, and therefore exempt under the FTCA. At this point, it is worth restating that the USC authorizes the USCG to deny the privatization of DGPS service and CFR explicitly states the statute.

Another exemption to the FTCA is the "misrepresentation exemption," which applies to the communication of misinformation upon which a recipient relies that causes economic loss such as lost profits. This exception has barred suits based on failure to give a warning to injured parties, and suits based on implied misrepresentation. In the context of DGPS, some actions will focus on personal injury and property damage rather than economic loss. In such cases, claims would be barred under the misrepresentation exemption if the negligent act were viewed as the dissemination of information. Arguably, broadcast of DGPS signals could be viewed as "misinformation."

Finally, it should be noted that to the extent that the DGPS service is developed by the private sector under reasonably precise specifications approved by the government, government contractors might be immunized from liability for design defects. The government contractor's defense also may bar state law, "failure to warn", claims. However, the courts are split as to whether this defense applies to non-military contracts.

6.5 Public-Private Arrangements

6.5.1 Private Sector Consortium

First, a critical mass of private sector entities (85% or so), with an interest in early implementation and the possible commercial opportunities that could flow therefrom, could form a consortium (probably a nonprofit corporation, see below), for the purpose of funding rapid DGPS service deployment. The members could buy shares in the organization through in-kind or cash contributions and the proceeds could be provided to USDOT via an earmarked contribution for land-based DGPS development. One possible structure would follow the Sematech and MCC models from the computer industry (discussed more fully in the next section). The members would have the technical capacity to design the system and receivers, and each would put up a percentage of the development cost. In return, the system would get built and a new market would develop. The members of the consortium selling DGPS equipment would be required to put a percentage of sales back into the consortium.

This model presents a number of problems. Obviously, the “free-rider” problem will be significant here unless there is strong industry support. Also, creation of the consortium may require an exemption from anti-trust laws.

6.5.2 Public/Private Partnership

Alternatively, a non-profit corporation with both public and private members could be formed (possibly including state and local governments as well as Federal), such as in the HELP Inc. case. Again, the “free-rider” problem may be significant, and involving multiple jurisdictions would likely be time consuming and unwieldy.

6.5.3 A Possible Solution

All of the foregoing argues for the following scenario: DOD transfers the Ground Wave Emergency Network (GWEN) sites to ACOE or USCG. As an intradepartmental transfer, such action makes the GWEN sites available to DGPS expansion at no acquisition cost, and at little or no exposure to base closure priority of use issues. USDOT funds the augmentation of the sites, either with government funds or through private-sector contributions (see discussion, below), and assumes financial responsibility for operations and maintenance. Performance of actual operations and maintenance services is contracted out to USCG, so that it may perform the same in concert with its existing sites.

Earmarking Gifts for DGPS - A related question is whether funds or equipment contributed for DGPS can be earmarked so that the donors would be assured of the intended use. This arises in the context of a gift to a Federal agency rather than a specific purpose, tax-exempt entity. The answer to this question may also provide a method of avoiding the problem discussed above regarding potential loss of tax deductibility if the donor receives an indirect benefit.

If the donor agency is an agency under the Department of Transportation, the gifts can be earmarked. Section 326 of Title 49 of the U.S. Code provides as follows:

§ 326. Gifts

The Secretary of Transportation may accept and use conditional or unconditional gifts of property for the Department of Transportation. The Secretary may accept a gift of services in carrying out aviation duties and powers. Property accepted under this section and any proceeds from the property must be used, as nearly as possible under the terms of the gift.

The Department has a fund in the Treasury. Disbursements from the fund are made on the order of the Secretary. The fund consists of: gifts of money; income from property accepted under this section and proceeds from the sale of that property; as well as income from securities under subsection (c) of this section.

On request of the Secretary of Transportation, the Secretary of the Treasury may invest and reinvest amounts in the fund in securities of the United States Government, or in securities whose principal and interest is guaranteed by the United States Government.

Property accepted under this section is a gift to or for the use of the Government under the Internal Revenue Code of 1954 (26 U.S.C. 1 et seq.).

The language of this section clearly requires the Secretary of Transportation to use the donation as nearly as possible within the confines of the terms of the gift. Thus contributions earmarked for DGPS will be used for that purpose if the contribution is to an agency of the Department of Transportation. The reference in section (b)(2) to the fund in the Treasury consisting of income from property appears to imply that property donated in kind would be sold and the proceeds deposited in the fund in the Treasury. However, there is no indication that this should be interpreted as a limitation on acceptable gifts to cash gifts or property that can be sold to generate cash. This provision in section (b)(2) does not appear to limit the first sentence of section (a), which clearly authorizes the Secretary of Transportation to accept conditional gifts of property. Thus, property (e.g., equipment) given for DGPS use should be acceptable under section (a)(1) and subject to earmarking for DGPS use rather than sale.

> Note: Statutory gift acceptance authority by an agency is an exception to the augmentation of appropriation. It might be helpful to point out that congressional appropriators may be resistant to allow USDOT to accept donations to any significant extent since this would bypass the appropriation process.

An interesting and beneficial part of this section is subsection (d), which states that property accepted is automatically classified as a gift under the Internal Revenue Code. Therefore, even though the donor may expect to derive benefit in the form of enhanced markets, the characterization of the gift as a contribution deductible for income tax purposes is safeguarded by this subsection (d). This shelter provides an added benefit to structuring the effort to develop DGPS around a system developed by FHWA, or some other USDOT agency, rather than a separate entity.

6.5.4 Why Should the Federal Government Establish and Operate the NDGPS Service?

This section of the report highlights major factors that justify a Federally owned and operated NDGPS Service.

- ***Authority By Public Law***: On October 27, 1997, the President signed a bill that became Public Law 105-66. Section 346 of this law authorizes the Secretary of Transportation to establish, operate and maintain Nationwide DGPS Service. This law also explicitly states that the NDGPS Service will be provided without the assessment of any user fees.

- ***"Market Failure" Issue***: The private sector failed to provide a Nationwide DGPS service that has all the attributes (coverage, accuracy and integrity) required for public safety applications e.g., navigation applications. It is important to understand that the current private DGPS service providers provide signal for positioning but not navigation. This service is not enough for example to implement PTS for train control which is a public safety application and human lives will rely on it. The private sector will not establish the NDGPS Service unless there is a return on investment. For the return on investment to be possible, the DGPS signal need to be encrypted. Encrypting the DGPS signal could be a liability nightmare since many public safety applications will rely on the signal. Moreover, the USCG DGPS signal is currently available to any user free of direct user fees. Above all, Public Law 105-66 Sec.346 (c) mandates that the NDGPS Service must be free of charge to the user. It is also important to note that currently no private DGPS service is offered with an integrity capability. Moreover, the private sector, may not be able to provide nationwide DGPS service that is adequate for public safety applications because of technical limitations. In the case of FM subcarrier service providers, there are not enough commercial FM stations nationwide to provide the nationwide coverage since the range of an FM station is approximately 30 plus miles. While in the case of satellite DGPS service providers, these satellites are geostationary and have shadowing problem if an obstacle i.e., tall building or trees is between the satellite and the receiver (user) on the ground.

- ***Code of Federal Regulations (CFR)***: According to 33CFR66.01-1(d) which states "With the exception of radar beacons (racons) and shore based radar stations, operation of electronic aids to navigation as private aids will not be authorized." The NDGPS Service is an expansion of the existing USCG DGPS system which includes 54 (44 sites in CONUS, 7 sites in Alaska, 2 sites in Hawaii and 1 site in Puerto Rico) operational Radiobeacon sites. All new sites (estimated 66 sites 12 of them in Alaska) will comply with the current USCG DGPS standards. Moreover, the NDGPS Service will be the basis for the implementation of Positive Train Separation (PTS) as a navigation aid. The purpose of PTS is to ensure ample spacing between trains to avoid collisions.

- ***National Security***: Public Law 105-66 Sec. 346 (c) (3) states "[the Secretary of Transportation may] in cooperation with the Secretary of Defense, ensure that the use of the NDGPS is denied to any enemy of the United States." Federal ownership of the NDGPS Service guarantees compliance with the above Public Law since the USCG with the assistance of the USAF (if necessary) can turn the NDGPS Service off after proper notification to all users. On the other hand, private ownership does not ensure such compliance.

- ***Spectrum Availability***: The USCG DGPS system uses the International Maritime Frequency (285 - 325 kHz). Maritime applications are the primary use of this frequency. Hence, the private sector would not likely be able to obtain authorization to use this maritime frequency.

6.6 Impact On Current Commercial DGPS Service Providers

Before launching into the details about DGPS service providers and their impact from the implementation of the NDGPS Service, it is essential to give the reader a basic understanding of the GPS/DGPS market. This market is relatively new and growing fast. Manufacturing and integration is the dominant portion of the GPS/DGPS economy. A nationwide DGPS Service that conforms to a universal standard will enhance the market for development of new and innovative products. A snapshot of the current market is offered below:

- **Equipment Manufacturers**: this category includes GPS and DGPS chip manufacturers, GPS and DGPS receiver manufacturers and antennas. GPS World, in January 1998 issue, lists 70 manufacturers that manufacture 429 receivers.

- **GPS/DGPS Integrators**: these are companies that utilize GPS/DGPS service to provide useful applications. For example, some companies use GPS/DGPS signal to provide Automatic

Vehicle Location (AVL) for many users e.g., emergency service providers and commercial fleet.

- **Software Developers**: it is true software development is part of the above two market categories, but software development include those companies that develop customized software for specific user e.g., farmer collecting data about the soil quality or a state law enforcement agency with a need to track, identify and display data back at headquarters about field officers.

- **Service Providers (Providers of DGPS signal):** refers to companies that provide a GPS/DGPS signal for a subscription fee. The signal is encrypted and only subscribers can access and use the signal. This category does not include companies that provide applications utilizing GPS/DGPS signal.

General market research shows that equipment manufacturers and integrators claim the largest piece of the market. The DGPS Implementation Team wasn't able to find a break down of market sales for each of the four market categories listed above. However, during market research, the Team found out that the number of companies providing DGPS signal for a subscription fee is very small (6) compared with the large number (over 100) of firms that are in the GPS market.

Commercial DGPS service is currently offered by companies utilizing both the FM subcarrier facilities of selected commercial broadcast FM radio stations and commercial satellite facilities. These services are fee based and distinguished for the most part by their signal dissemination methods.

6.6.1 FM Subcarrier Service Providers

There are two principal FM subcarrier service providers, Differential Corrections Incorporated (DCI) and Accqpoint Incorporated. Each commercial service provider offers its subscribers access to a differential correction signal via a FM subcarrier. A potential national DGPS service based upon an FM subcarrier system is difficult to quantify because a number of commercial FM stations are reluctant to lease their FM subcarrier and achieving a ubiquitous national coverage may not be feasible. Each broadcast FM station typically has a robust broadcast range of approximately 30 plus miles, depending upon terrain.

DCI provides three levels of correction services:

- Basic which offers an accuracy of 10 meters
- Intermediate which offers an accuracy of 5 to 10 meters
- Premium which offers an accuracy less than 1 meter

The primary competition for the correction service comes from Accqpoint (land) and Micrologic (marine). Partners of DCI are identified to be Metro Information Services, Trimble Navigation Ltd., Volvo, UK Radio Authority, Canadian Broadcast Corp., Finnish Broadcast Corps, and Singapore's SIM Communication Pte Ltd., and Minnesota DOT (for whom it provides paging services to support MinnDot's traveler information program).

Accqpoint's parent company is CUE Network Corporation based in Irvine, CA. CUE paging provides messaging and information services nationwide. Accqpoint's main business base is offering DGPS provider services, nationwide messaging, and information services.

Accqpoint's competitors are DCI and Micrologic (marine vessels). Its partners are CUE; Leica; and John E. Chance & Associates. Accqpoint's services in traffic information dissemination projects are TRW, SONY, and Thomas Brothers Maps.

Note: John E. Chance & Associates is a wholly owned subsidiary of Fugro (a Netherlands corporation). Omnistar, which offers commercial GPS augmentation services using geostationary satellite platforms, is also a wholly owned subsidiary of Fugro.

Accqpoint offers a 1-meter accuracy DGPS service that includes the rental of receiver equipment.

Although literature provided by FM subcarrier service providers states that FM subcarrier service will have 100% coverage of CONUS by 1996, realty is that FM subcarrier DGPS service coverage is offered primarily in heavily populated urban areas with very little coverage offered in rural areas. For example DCI would need 28 additional stations in South Dakota to give contiguous coverage of the state and it would still leave major coverage gaps between populated areas. Many of the other western states and mountainous regions presently have little to no FM subcarrier DGPS service coverage outside of their principal cities.

6.6.2 Impact of DGPS Expansion on FM Subcarrier Market

The impact on information systems that are in the FM subcarrier market will be minimal. These systems include paging and data systems in addition to DGPS distribution. In the FM DGPS subcarrier marketplace, the expansion of DGPS service may have an effect on its 1 - 100 meter service offering. There should be no impact on higher accuracy service (less than one meter).

DCI's current business is based upon offering a fee-based DGPS FM subcarrier service with additional charges for hardware. DCI has operational and trial DGPS service business base(s) in Canada, U.K., Australia, and several European countries in addition to the U.S. and Canadian markets. Market analysts have watched DCI explore new applications in lieu of its DGPS service.[23] The DCI RBDS system allows capacity for paging and time services.

Accqpoint has a large parent company in CUE Network Corporation. CUE's controlling shareholder interest is held by Radio Satellite Network (of Toronto, Canada). CUE provides nationwide and regional messaging, and paging services throughout North America. Accqpoint, a company of five employees, seemingly should handily continue its business operations and DGPS market share due to its affiliation with CUE Network Corporation.[24]

There are still some advantages to the FM subcarrier system. The FM receiver is the least expensive hardware. However, the subscription fees of $600/year may offset this advantage. The FM station hardware is inexpensive enough for local users to buy and operate their own services. FM subcarrier distributors are also using existing FM antenna platforms to mount their base stations to reduce both installation and operating costs.

6.6.3 Satellite Service Providers

Omnistar, based in Houston Texas, is a national wide-area DGPS service provider. The Omnistar system has eleven (11) GPS monitoring sites that send GPS corrections by leased telephone line and Very-Small Aperture Terminals (VSAT) to a Houston based Network Control Center. The Control Center checks and uplinks the corrections via spread spectrum radio to a system of three geostationary satellites. These

[23]Reference: World ITS Markets, 1995

[24]Reference: World ITS Markets, 1995

satellites transmit an encrypted signal in the C-band frequency (3,750-4,250 MHz). On the downlink, users of this system have an omnidirectional antenna and Omnistar receiver that feeds corrections into the RTCM SC-104 port of a differential capable GPS receiver. Based upon a discussion with a representative of Oministar, it appears that this service does not offer an integrity alarm capability.

Omnistar's DGPS service is offered directly to end-users as well as by John E. Chance & Associates, which is a subsidiary of the Fugro-USA group. The primary business of the John E. Chance group is geotechnical and geoenvironmental engineering where service is provided to offshore, land, private and public surveying, and positioning of platforms.

The Racal Survey USA "Landstar" system is a recent entry into the DGPS service market (February 1996). Racal Survey-USA provides DGPS service to terrestrial users in North America via its "Landstar" system. Racal Land Survey (RLS) is a subsidiary of the UK-based Racal Corporation. RLS also provides DGPS correction services internationally to markets in New Zealand, Indonesia, and Papua New Guinea.[25]

The Racal system of nineteen monitoring stations feeds GPS data to the RLS Houston control station. Corrections are uplinked to the American Mobile Satellite Corporation SkyC system of geosynchronous orbiting satellites, which transmit the differential corrections in the L-Band frequency (1,525 to 1,559 MHz) to users throughout North America. The Landstar cell network is designed to ensure that users achieve a sub-meter accuracy up to 250 miles away from the reference station.

RLS is headquartered in Houston, Texas and has a common address with NCS International, Inc., a recently acquired Survey and Positioning company employing a staff of 88 people and providing marine exploration, construction, and engineering services. NCSI is a group of companies consisting of two systems and development companies, Meridian Ocean Systems, and Pulse Research Navigation Systems. Pulse Research specializes in GPS-related software products.[26]

NCSI provides DGPS correction service to marine users in the Gulf of Mexico. This is done through its Micronet DGPS data link network (non-satellite-based system) where corrections are transmitted to users with differential-capable RTCM SC-104 GPS receivers. The Racal Survey-USA "Landstar" system is a satellite-based DGPS system that provides correction services to land users.

6.6.4 LF/MF Radio Beacon Service Providers

Communications Systems International Inc. **(**CSI) is headquartered in Calgary, Alberta, Canada. The company designs and manufacturers DGPS reference station and receiver products based on the RTCM SC-104 standard.

CSI is also a commercial service provider of DGPS corrections service in that it is currently providing DGPS beacon service using an encrypted signal at two locations in Canada and one in Argentina. It plans to establish a third beacon signal in Canada in the near future.

The affordability of its products is due, in part, to its focus on government sponsored beacon systems throughout the world, which allow consumers to take advantage of government sponsored DGPS corrections service. CSI pursues an open systems design and engineering philosophy that allows the company to integrate leading GPS receiver technology within its systems. CSI has achieved worldwide distribution of its products by teaming with large, multi-national strategic partners.

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[25] Source: Global Positioning & Navigation News, May 2, 1995

[26] Source: NCS International Web site address, WWW.nsci-survey.com

According to a spokesperson for CSI, from a business perspective, expansion of the current USCG/ACOE DGPS service to a nationwide service in the U.S. will have a positive impact on CSI -namely an increase of sales in an integrated chip it recently developed for other equipment manufacturers. The spokesperson did indicate that the sunk capital investment for the establishment of a new DGPS service in Winnipeg, Canada which also targets the Duluth, MN region could be imperiled if an open system service is installed in the near future in the U.S.

6.6.5 Impact of LF/MF DGPS on the Satellite DGPS Market

Satellite DGPS service providers offer service to both land and marine users. Both Omnistar and Racal are subsidiaries of larger parent companies whose business base fills niche markets in marine exploration, surveying, and environmental engineering applications.

It is expected that the implementation of a national LF/MF DGPS beacon system without user fees will have a moderate impact and only on satellite service providers whose business base is primarily in the terrestrial domain.

The prime business base for the Omnistar DGPS market is the oil producing platforms in the Gulf of Mexico. This base will not be affected by CONUS landside LF/MF DGPS distribution. The nascent inroad into agriculture by the satellite-based systems could possibly be limited in their future market growth if LF/MF DGPS provides subscription-free service in the midwestern regions. LF/MF DGPS service is already available from the USCG/ACOE LF/MF network in the coastal regions and in the Mississippi and Missouri basin inland waterway regions. Presently cost is the driving factor with satellite receiver hardware being more expensive than LF/MF receiver hardware and satellite systems requiring relatively high subscription fees. The Loral LINCS program, which is not due for its first satellite launch until 1997 with an initial operating capability in 1998, is forecast to provide DGPS at low cost but the primary business base is the information transfer capability, not the DGPS distribution system.

6.7 Conclusions

The provision of a standardized nationwide DGPS service will likely have a significant beneficial effect on the GPS/DGPS equipment manufacturers, integrators and software developers market. Additionally, there is every reason to presuppose that synergistic benefits will be enjoyed by the national economy through improved efficiencies in areas such as public safety, transportation, geodetic services, and agriculture.

Although there are a number of methods that could possibly be utilized to implement and maintain a nationwide DGPS service, the most practical approach is to implement a service that is installed and maintained by the Federal government. The installation period will be shorter and compliance with recognized standards is guaranteed.

With regard to a possible negative effect on current DGPS service providers, the expansion of the USCG service with an open signal that is provided at no cost to the end user may reduce the size of the potential market for commercial service providers. However, based upon current knowledge of the target market of theses commercial service providers as well as the ability of commercial service providers to furnish a quality of service down to the submetric positioning accuracy it is obvious that a market potential will remain.

It is worth noting that in an October 27, 1997 memorandum to Frank Raines, Director of OMB, Charles R. Trimble, Chairman of the U.S. GPS Industry Council stated ".....some private sector models are more successful than others. .... the use of the FM subcarrier proved not to be reliable in the field. This lack of performance to the customer has driven the private FM subcarriers to their current economic state, NOT the threat of competition from the U.S. government. ......From our industry perspective, it would be a severe disservice to the U.S. taxpayer to impede the implementation of a nationwide DGPS, especially in such a cost effective manner"

7. COST/BENEFITS

7.1 Costs

Implementation of DGPS reference stations in areas not covered by the existing U.S. Coast Guard/Army Corps of Engineers' DGPS service will involve appropriating funds to pay for establishment of the additional sites. As previously stated, the opportunity to establish additional DGPS radiobeacon sites relatively inexpensively is available through the reuse of USAF decommissioned Ground Wave Emergency Network (GWEN) sites. As a result, geographic coverage of the current USCG/ACOE DGPS service could be expanded in a very short time and the cost of providing Nationwide DGPS service would be significantly reduced. It should be noted however that additional new sites would still be required in order to furnish complete nationwide coverage. There are three possible implementation scenarios:

- Scenario #1: Obtaining all new sites and equipment
- Scenario #2: Using selected GWEN sites and equipment plus obtaining some new sites and equipment
- Scenario #3: Using selected GWEN sites and equipment plus obtaining some new sites and relocating surplus equipment from other GWEN sites to the new sites

An important difference between new sites (USCG-like site) on one hand and GWEN site and new site with moved GWEN equipment on the other hand is the coverage area. USCG-like sites provide smaller coverage area due to shorter antenna and lower antenna efficiency. This fact makes GWEN sites even more cost effective.

7.1.1 Cost Estimating Methods and Sources

Costs can be categorized into three primary components: capital, operating and maintenance costs. Furthermore, these costs are different among new, converted GWEN, and relocated GWEN sites equipment.

The establishment of a new DGPS radiobeacon site involves planning, design and construction in a ground-up manner including an environmental impact study. Capital costs for a new site would include all costs for site planning, design, antenna systems, generator, electronic equipment, equipment shelters, and other items.

The conversion of an existing GWEN site would entail the nominal planning, design and construction costs associated with converting the existing facilities and structures to conform to the requirements of a DGPS broadcast site. A converted GWEN site would have the antenna and ground plane, equipment shelter, and generator thus eliminating these capital costs.

Relocated GWEN site equipment would have some of the savings associated with a converted GWEN site, but will have capital expenditures associated with new site acquisition as well as equipment moving expenses.

It is important to note that the calculated capital costs included in this study consider the cost of expanding an existing USCG control station to monitor the added DGPS radiobeacon sites (total of 66 sites to cover CONUS and parts of Alaska).

Site operating costs include typical site costs such as electric utilities, communications, property lease, training, and travel as well as control station staff.

Site maintenance costs include the costs for both routine and emergency maintenance of electronic equipment, facility and other on-site structures and equipment.

The cost components of capital, operating and maintenance costs are computed separately, for an all new site, a converted GWEN site, and establishing a new site utilizing relocated GWEN site equipment.

Specific cost items are significantly different between a new site and GWEN facility due to differences in the infrastructure components and installation complexity.

Capital, operating, and maintenance costs are based on current costs of the USCG DGPS system.

7.1.2 Approach and Methodology

The following assumptions are used in estimating cost for each of the three possible implementation scenarios mentioned above:

- Sixty-six (66) DGPS sites will be established in two phases.

- Phase I includes establishing thirty-one (31) DGPS sites, expansion of the USCG control station in Alexandria, Virginia, depot support and annual operating, maintenance cost for (33) sites and operating cost for the control station. It is anticipated that Phase I will be completed by end of year 2000. While Phase II includes establishing thirty-five (35) DGPS sites and operating, maintenance cost for sixty-six (66) sites and operating cost for the control station. It is anticipated that this phase will be completed by end of year 2002.

- Twelve (12) of the sixty-six (66) DGPS sites will be located in the state of Alaska.

- The cost of establishing a DGPS site in Alaska is estimated to be one and one-half (1.5) times the cost of establishing the same site in CONUS. This is due to the rugged terrain and harsh conditions in the State of Alaska.

- Twenty percent (20%) contingency is added to capital and annual costs to cover any unanticipated costs.

7.1.3 Calculations

Based on the above assumptions and unit costs listed in Table 3 below, a detailed cost calculation for each scenario is provided below.

Table 3. Unit Cost

Description	*Capital Cost*	*Annual Operating Cost*	*Annual Maintenance Cost*
GWEN Site	$196,529	$17,400	$27,000
New Site/Moved GWEN Equip.	$404,229	$17,400	$27,000
New Site/New Equip.	$423,729	$17,400	$27,000
Control Station Expansion	$144,260	$948,895	-
Depot support	$694,248	-	-

Note: Refer to appendix C for detailed break down of each unit cost

Scenario #1 (all new sites and new equipment):

Capital cost of 66 new sites = (54 + 12*1.5) * $ 423,729/site = $ 30,508,488

Capital cost of control station expansion = $ 144,260

Capital cost of depot support = $ 694,248

Subtotal of capital cost = $ 30,508,488+ $ 144,260 + $ 694,248 = $ 31,346,996

20% contingency = $ 31,346,996* 20% = $ 6,269,399

Total capital cost = $ 31,346,996+ $ 6,269,399= **$ 37,616,395**

Annual control station operation cost = $ 948,895

Annual operating cost for 66 site = 66 * $ 17,400/site = $ 1,148,400

Annual maintenance cost for 66 site = 66 * $ 27,000/site = $ 1,782,000

Subtotal of annual O&M cost = $ 948,895 + $ 1,148,400+ $ 1,782,000 = $ 3,879,295

20% contingency = $ 3,879,295* 20% = $ 775,859

Total annual O&M cost = $ 3,879,295 + $ 775,859 = **$ 4,655,154**

Scenario #2 (Converted GWEN sites plus new sites with new equipment):

Capital cost of 33 new site with new equipment = (21 +12 * 1.5) * $ 423,729/site = $ 16,525,431

Capital cost of 33 GWEN sites = (33) * $ 196,529/site = $ 6,485,457

Capital cost of control station expansion = $ 144,260

Capital cost of depot support = $ 694,248

Subtotal of capital cost = $ 16,525,431+ $ 6,485,457 + $ 144,260 + $ 694,248 = $ 23,849,396

20% contingency = $ 23,849,396 * 20% = $ 4,769,879

Total capital cost = $ 23,849,396+ $ 4,769,879 = **$ 28,619,275**

Annual control station operation cost = $ 948,895

Annual operating cost for 66 site = 66 * $ 17,400/site = $ 1,148,400

Annual maintenance cost for 66 site = 66 * $ 27,000/site = $ 1,782,000

Subtotal of annual O&M cost = $ 948,895 + $ 1,148,400+ $ 1,782,000 = $ 3,879,295

20% contingency = $ 3,879,295* 20% = $ 775,859

Total annual O&M cost = $ 3,879,295 + $ 775,859 = **$ 4,655,154**

Scenario #3 (Converted GWEN sites plus new sites using relocated GWEN equipment or new equipment):

Capital cost of 30 GWEN sites = 30 * $ 196,529/site = $ 5,895,870

Capital cost of 28 new sites with moved GWEN equipment = (16 +12 * 1.5) * $ 404,229/site

= $ 13,743,786

Capital cost of 8 new USCG-like sites with new equipment = 8 * $ 423,729/site = $ 3,389,832

Capital cost of control station expansion = $ 144,260

Capital cost of depot support = $ 694,248

Subtotal of capital cost = $ 5,895,870 + $ 13,743,786 + $ 3,389,832 + $ 144,260 + $ 694,248

= $ 23,867,996

20% contingency = $ 23,867,996 * 20% = $ 4,773,599

Total capital cost = $ 23,867,996 + $ 4,773,599 = **$ 28,641,595**

Annual control station operation cost = $ 948,895

Annual operating cost for 66 site = 66 * $ 17,400/site = $ 1,148,400

Annual maintenance cost for 66 site = 66 * $ 27,000/site = $ 1,782,000

Subtotal of annual O&M cost = $ 948,895 + $ 1,148,400+ $ 1,782,000 = $ 3,879,295

20% contingency = $ 3,879,295* 20% = $ 775,859

Total annual O&M cost = $ 3,879,295 + $ 775,859 = **$ 4,655,154**

Table 4 below contains a summary of the cost estimate for each of the three implementation scenarios listed above.

Table 4. Summary of Cost Estimate for Three Implementation Scenarios

Scenario	Capital Cost	Annual Operating Cost	Annual Maintenance Cost
#1 All New Sites & Equipment	$ 37,616,395	$2,516,654	$ 2,138,400
#2 GWEN sites plus New Sites & New Equipment	$ 28,619,275	$2,516,654	$ 2,138,400
#3 GWEN Sites plus New Sites & Relocated GWEN Site Equipment	$ 28,641,595	$2,516,654	$ 2,138,400

The above cost analysis for all implementation scenarios shows that Scenario #3 (Converted GWEN sites plus new sites with relocated GWEN equipment) is the most cost-effective scenario. Moreover, there is a unique advantage for using GWEN sites, which is nationwide coverage can be provided with a reduced number of sites. This is possible because a GWEN site is more efficient and has larger coverage area than an USCG-like DGPS site.

7.1.4 Life Cycle Costs.

A fifteen-year life cycle is used in conducting this cost benefit analysis. All costs are converted to present value even though not all costs are expended at the same time. Capital cost will be incurred in two phases. The first phase will provide single coverage nationwide. The second phase will provide dual signal coverage nationwide (sometimes referred to as "redundant coverage"). The operational benefit to be derived from dual coverage is dramatically improved signal availability. Based upon engineering computations for equipment components as well as system design, the availability of the differential signal in a single coverage system has been theoretically determined to be 99.7%. Based upon the same parameters, the availability of the differential signal in a dual coverage system is calculated to be 99.999%.

Note: "Coverage" is the term used to describe the concentric geographical area over which signals from a single radiobeacon station are present. "Dual coverage" connotes that signals from two independent radiobeacon stations are present within the same geographical area.

Table 5 below summaries system cost during the fifteen-year life cycle.

Description/Activity	*Unit Cost*	*FY 1998*		*FY 1999*		*FY 2000*		*FY 2001*		*FY 2002*		*FY 2003 & Beyond*
		QTY	$$$	QTY	$$$	QTY	$$$	QTY	$$$	QTY	$$$	$$$
Installation Cost of :												
GWEN Site in CONUS	$196,529	3	$589,587	3	$589,587	8	$1,572,232	8	$1,572,232	8	$1,572,232	
Moved GWEN Site in CONUS	$404,229	3	$1,212,687	0		2	$808,458	6	$2,425,374	5	$2,021,145	
New Sites in CONUS	$423,729	0		5	$2,118,645	3	$1,271,187	0	$0	0	$0	
Moved GWEN Site in Alaska	$606,344	0		0		4	$2,425,374	4	$2,425,374	4	$2,425,374	
Control Site Expansion	$144,260	0		0	$144,260	0		0		0	$0	
Depot Initial Spare Parts	$694,248	0		0	$694,248	0		0		0		
Sub-total	--		*$1,802,274*		*$3,546,740*		*$6,077,251*		*$6,422,980*		*$6,018,751*	
Installation Contigency (20%)	--		$360,454.80	0	$709,348.00	0	$1,215,450.20	0	$1,284,596.00	0	$1,203,750.20	
Installtion Sub-total Cost		***6***	***$2,162,729***	***8***	***$4,256,088***	***17***	***$7,292,701***	***18***	***$7,707,576***	***17***	***$7,222,501***	
O&M Cost:												
Annual Site O&M Cost		6	*$266,400*	14	*$621,600*	31	*$1,376,400*	49	*$2,175,600*	66	*$2,930,400*	*$2,930,400*
Annual Control Station Opr. Cost			0		0		$948,895		$948,895		$948,895	$948,895
Sub-total of O&M Cost			$266,400		$621,600		$2,325,295		$3,124,495		$3,879,295	$3,879,295
O&M Contigency (20%)			$53,280		$124,320		$465,059		$624,899		$775,859	$775,859
Sub-total Site O&M Cost			$319,680		$745,920		$2,790,354		$3,749,394		$4,655,154	$4,655,154
Total Installtion + O&M Cost			**$2,482,409**		**$5,002,008**		**$10,083,055**		**$11,456,970**		**$11,877,655**	**$4,655,154**

7.2 Benefits Assessment

7.2.1 Approach and Methodology

7.2.1.1 Study Basis

The principal purpose of the DGPS implementation program will be to complete the coverage of the CONUS and parts of Alaska beyond those geographical areas currently served by the existing US Coast Guard (USCG)/Army Corps of Engineers (ACOE) differential correction service.

As noted elsewhere in this report, it is estimated that the current USCG/ACOE DGPS service extends to roughly 55% of the CONUS surface area and 15% of the Alaskan surface area. It is estimated that the current coverage serves approximately 65% of the CONUS population and 57% of the Alaskan population. These coverage estimates are based upon simulation models developed by the Department of Commerce's Institute for Telecommunication Sciences (ITS) of the National Telecommunications and Information Administration (NTIA) office in Boulder, Colorado. The proposed additional coverage would occur primarily in the Plains states, Mountain states, about half of Appalachia, and the western half of Alaska.

As also noted elsewhere in this report, the current USCG/ACOE system only provides "single coverage." The system architecture associated with the proposed service provides for "dual coverage," resulting in substantial improvements in the reliability of the current system.

> Note: "Coverage" is the term used to describe the concentric geographical area over which signals from a single radiobeacon station are present. "Dual coverage" connotes that signals from two independent radiobeacon stations are present within the same geographical area.

From an economic standpoint, the primary benefits that would accrue (over and above those already enjoyed in the areas of existing USCG/ACOE coverage) are new opportunities for DGPS use, where alternative public or private DGPS service is either unavailable, prohibitively expensive for most uses, or technically impractical for a particular application. Because DGPS systems are not in widespread use in those areas which would be newly covered by the proposed service, this analysis focuses on the benefits associated with new opportunities for DGPS use.

Within this category, the economic analysis focuses on the *net* benefits obtained at an "efficient" level of DGPS utilization. This essentially means the difference between the gross benefits (for example, the economic value of increased operating efficiencies for a user) minus any fixed and/or variable costs to the user for employing DGPS, such as the costs of DGPS receivers, subscription services, associated computer facilities, development of databases, etc.

A simplified model of this is illustrated in Figure 5 below.

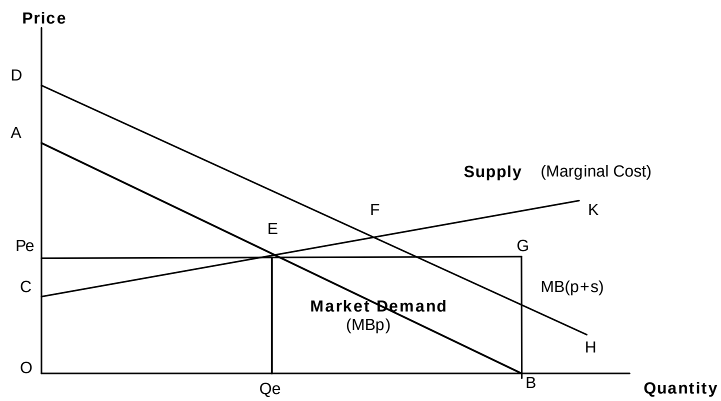

Figure 5. Net benefit calculation

In the figure, the line AB is the private market demand for DGPS. The market demand curve can also be interpreted as the marginal private benefit (MBp) of DGPS. The supply curve CK can also be viewed as the marginal cost curve for DGPS. The line DH represents the marginal private plus social benefit curve, with the value of social benefits (i.e., benefits that are not captured by private market transactions) equal to the vertical distance AD. The private market attains equilibrium where the supply and demand curves intersect, at point E. This is the point where the quantity demanded just equals the quantity supplied at a given price. The equilibrium quantity is Qe.

In this model, private net benefits would equal the area ACE, the sum of consumer and producer surplus.[27] Viewed from a different perspective, private net benefits are the difference between total benefits (AOQeE) and total costs (COQeE).

7.2.1.2 Basic Approach

Referring back to the conceptual model illustrated in Figure 1, in the absence of information about the shapes of demand curves within particular markets, the net benefits of DGPS use are best approximated, as a practical matter, by the difference between estimated gross benefits and investment plus operations and maintenance costs, for those users for whom marginal benefits would exceed marginal costs. Since the shape of the demand curve is not known, consumer surplus cannot be accurately measured, although it can be approximated in some instances where additional information is available.

It is important to emphasize that, while the overall market of potential users of DGPS services consist of those individuals, businesses and organizations who could *technically* employ DGPS systems, not all will. Only those potential users for whom the realizable benefits exceed the costs will use the system; thus, the number of beneficiaries is limited to a subset of the total potential DGPS user market. Here again, the efficient level of DGPS use (Qe in Figure 1) cannot be identified with great confidence due to insufficient information about the demand function. However, for estimation purposes, corrections can be made by the use of conservative assumptions about market penetration rates.

[27] In fact, private markets would not generate all of the net benefits that could be obtained from DGPS, where there are social benefits not included in market transactions. With a subsidy equal to DA, total benefits (private plus social) could be increased to the area of the triangle DCF.

Both of these important economic concepts – calculation of net benefits (gross benefits minus user costs) and market penetration limited to those users for whom benefits exceed costs – are utilized to the maximum extent possible in the estimation of benefits, as part of the benefit-cost analysis.

7.3 Categories of Benefits

Consistent with the requirements of the Office of Management and Budget (OMB) Circular A-94, the DGPS Policy and Implementation Team looked at several areas of relevant benefits. The Nationwide DGPS Service has the potential to deliver benefits in the following categories:

- Cost Savings
- Life Savings
- Efficiency Increase
- Environmental Impact
- Transportation Economic Benefits

7.3.1 Cost Saving

The magnitude of cost savings to be realized by an agency depends to a great extent upon the mission of that agency and the technology application. For example, an agency using only traditional surveying methods has a potential savings greater than an agency already using post-processing DGPS methods. Also some agencies need only a basic DGPS receiver to benefit from the system (e.g., EPA applications) while other users must provide additional equipment to utilize a Nationwide DGPS service as would be the case in the railroad industry Positive Train Separation (PTS) system.

7.3.2 Life Savings

Nationwide DGPS service will help in saving lives. Preliminary estimates indicate that approximately 3% of the total annual highway deaths (41,000) can be averted using a NDGPS.[28] DGPS combined with a communications link in automobiles could automatically notify emergency personnel as to exactly where an accident is located, as it occurs, thus greatly reducing the notification time. Law enforcement can locate and respond to accidents more quickly.

Several testimonials have been received from Civil Air Patrol volunteers and amateur radio operators ("Hams") regarding the potential benefits of a nationwide DGPS service during Search and Rescue (SAR) operations. As to how many lives will be saved nationwide will depend on the extent that DGPS is used; but several contacts predict the number is significant.

Another example of benefits is reducing railroad accidents. DGPS will be the basic enabling technology for PTS, which is on the "Most Wanted List" of the NTSB. The chairman of NTSB reported that train accidents in the first six months of 1996 resulted, among other things, in 26 fatalities. NTSB investigators stated that PTS could have prevented such losses. Moreover, DGPS will enable emergency response teams to react faster to incidents and disaster areas (e.g., floods and earthquakes) where response time is very critical in saving lives.

7.3.3 Efficiency Increase

Almost all agencies contacted stated that real-time DGPS will increase their efficiency. This increase is attributable to several factors such as reduction of man-hours used for post-processing geodetic data or

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[28] The National Highway Traffic Safety Administration is currently conducting a study of this issue which will be completed by end of 1998.

increase of system capacity; e.g., PTS will enable the railroads to operate more trains using the same infrastructure, or use of less pesticides and fertilizers by farmers. Another example of efficiency improvement is reported by an EPA contact who stated that real-time DGPS only takes 50% of the time for doing the same quantity of work as that performed by post processing. Yet another example is using DGPS to develop forest fire mitigation plans for efficient deployment of manpower and aircraft resources. Finally, there is time savings associated with returning to and finding a specific site (e.g., resampling of soils or contamination sites). These savings may be minutes or hours depending on the site location and terrain.

7.3.4 Environmental Impacts

The environment is another area that will experience a large positive impact from a Nationwide DGPS service. Quantifying environmental impact is very difficult but the following two examples will illustrate the point. First, this system will be used to accurately and expeditiously survey hazardous sites, i.e., oil spills and contaminated water wells. Doing so will speedup quantifying the problem and consequently taking the required corrective action. In the case of spills, time is very critical in assessing the situation and conducting the clean up process. The second example is using DGPS in precision farming. Utilizing DGPS enables farmers to spread pesticides in smaller areas (where needed only) near but outside of environmentally sensitive areas thus reducing the amounts of pesticides used. This will reduce water contamination and reduce environmental pollution.

7.3.5 Transportation Economic Benefits

Potential benefits from the NDGPS Service in transportation can be categorized in four groups:

1. Transit
2. Emergency Response and Mayday
3. Infrastructure Management on Highways
4. Commercial Fleet Management.

Potential uses and examples of each category are discussed below. It is worth noting that there is an overlap among some of the benefit categories. For example, cost savings, life savings and efficiency increase can be found in transportation applications.

7.3.5.1 Transit Applications

Experts from several transit agencies that are using Automatic Vehicle Location (AVL), or are planning to use AVL, were interviewed. In addition, experts working in the transit industry, such as academicians and system integrators, were also interviewed. These individuals stated that an accurate location technology, like DGPS, is needed for AVL, automated annunciation, traffic signal priority, and Automatic Passenger Counters (APC).

An AVL/computer-aided dispatch system allows transit managers to pinpoint their transit vehicles on a computerized map. Because the map's latitude and longitudinal data may not be accurate, and because a transit vehicle's reported latitude and longitudinal location may not be accurate, map matching is needed. Map matching snaps the transit vehicle's reported location to the map's nearest street location. In many cases, streets may be close together and map matching may erroneously locate the transit vehicle on the map if standard GPS is used. Therefore, DGPS is needed to properly use an AVL/computer-aided dispatching system. In addition, DGPS is needed to perform schedule adherence.

Many times dead reckoning and GPS are used together as a means of AVL. Dead reckoning does not necessarily increase the accuracy of the AVL system. DGPS is required to increase the accuracy of the

AVL system. Dead reckoning provides a means to continue monitoring a vehicle's location when the GPS signal is lost.

> Note: A GPS signal may be lost when the signal is blocked by a large structure, such as a tall building or a heavy canopy of tree foliage.

Another transit application that requires accurate location data is on-board automated annunciation systems. An on-board transit vehicles, an automated annunciation system provides announcements (visually and/or audibly) at transit transfer points and major stops as the vehicle approaches a location. Different technologies may be used to trigger announcements. Beacons situated along routes at announcement locations is one method. However, a beacon-type system is expensive to maintain. Also, routes change over time due to construction activity or changing passenger patterns so the beacons must be relocated. A DGPS-based system is more flexible hence more popular among transit agencies.

Traffic signal priority systems give transit vehicles limited control over traffic signals. These systems extend the green phase or shorten the red phase upon the arrival of a transit vehicle that is running behind schedule, thus allowing the vehicle to make up time. Control over the traffic signal may be initiated by the transit vehicle operator (the operator pushes a button), or automatically using AVL and schedule adherence. An automated traffic signal priority system requires accurate vehicle location data. Accurate vehicle location data may be obtained using beacons placed at locations prior to traffic signals. However, for this application, a beacon-based traffic signal priority system is not cost effective.

Automatic Passenger Counter (APC) systems automatically record the number of passengers entering and exiting the transit vehicle at a particular time and location. Therefore, an APC system is integrated with a transit vehicle's AVL system. Because some bus stops are spaced closely together, an accurate AVL technology is necessary to accurately record the movement of passengers. The most feasible AVL system to use with APCs is a DGPS-based system.

Accurate AVL technologies in addition to DGPS may exist. DGPS-based AVL systems are preferred by most transit agencies. " … with most new [AVL] systems using a GPS-based location process."[29] Transit authorities in Milwaukee and Denver have spent $8.3 million and $11 million, respectively, on DGPS-based vehicle location systems to increase the safety and efficiency of transit bus fleet management.[30] The GAO report stated that " According to a Federal Transit Administration [FTA] official, other transit agencies around the country are considering installing similar bus tracking systems, which are 80% federally funded."[31] According to a FTA official, there are around 450 transit authorities of various sizes nationwide. It is unclear how many of the 450 transit authority plans to install a DGPS reference station. Each DGPS reference station costs $30,000 to set up with 80% of the cost funded by the Federal government.

7.3.5.2 Emergency Response and Mayday Applications

Emergency management services, such as fire, ambulance, and police, use AVL/computer-aided dispatching systems to dispatch their emergency vehicles to incident locations. The systems help dispatchers identify the closest unit to the scene. This saves precious time. Navigation of emergency

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[29] Intelligent Transportation Infrastructure Benefits: Expected and Experienced, Prepared under contract by the MITRE Corporation and sponsored by the Federal Highway Administration, January 1996.

[30] Global Positioning Technology, Opportunities for Greater Federal Agency Joint Development and Use, GAO/RCED-94-280, General Accounting Office, September 1994, page 12.

[31] Global Positioning Technology, Opportunities for Greater Federal Agency Joint Development and Use, GAO/RCED-94-280, General Accounting Office, September 1994, page 12.

service vehicles in remote areas has the potential to benefit from the Nationwide DGPS open system. Locating addresses in remote areas can often be very difficult, and use of in-vehicle navigation could significantly reduce the time it takes to respond to emergency calls.

The effectiveness of DGPS in locating lost hikers in remote areas is the primary public safety issue of Creighton Miller of the South Dakota DOT Accident Records Division. In the winter of 1996, a woman stranded in her car in a snow bank in South Dakota almost died before she was located by triangulation on her cellular phone signal. Even after she was located by helicopter it was difficult to tell the ground searchers how to find her in the open territory covered with deep snow. This is a problem on many of the roads in the open western states. John O'Mara of the Montana DOT mentioned the same problem of locating accidents and victims on the open highways. The accurate GIS mapping of these highway systems is in progress in several states that have been contacted. The requirement for post processing of data to make these maps accurate is a major problem. Mapping functions for secondary and county roads is a major problem because these roads are frequently not equipped with mile markers like the state and interstate road systems. Mapping efforts are underway in Montana, South Dakota and Texas.

Another example of how GPS is beneficial in emergency response is the Fire Department in Dallas, Texas. The Department's first encounter with GPS-based AVL was in 1991. Mr. Dee Morrison, systems analyst for the Dallas Fire Department, said that in an incident the response time using AVL was 2.5 minutes while without AVL the response time could have been four to five minutes.[32] In 1996, the Dallas Fire Department added in-vehicle units to its fire trucks, engines, and chiefs' cars. AVL proved its effectiveness in shortening response time and hence saving lives. AVL made it possible for ambulance 706 to be on the scene of an accident in 43 seconds. Prior to the use of AVL it would have taken at least five minutes for ambulance 703 to get the scene. "Rescuers say this patient is alive today because AVL could identify the closest unit."[33] When it came to quantifying the system benefits, Mr. Morrison said, " It is hard to absolutely quantify the life saving benefits of the AVL system."[34] But he gave an example of those benefits, "For the same quantity of ambulances, the magnitude of calls into the dispatching center over a 3 year period rose from 111,172 to 125,558 and the average response time fell from 5.24 minutes to 5.11."[35] In California, where man-made and natural disasters are common, "… [disaster] crews have begun using DGPS to record the precise location of unsafe bridges… to help coordinate immediate disaster response as well as to keep record for future analysis."[36]

Rural areas have the potential to benefit the most from GPS/DGPS technology to locate and assist persons with medical needs. According to Dr. Dan Schlager, "…70% of trauma-induced deaths in the U.S. occur in rural areas, even though 70% of the U.S. population live in urban areas."[37] Moreover, the current trend of closing rural U.S. hospitals as a result of hospital consolidations (e.g., by mergers) will undoubtedly have a deleterious effect on care for critically ill trauma patients.[38] The inherent low cost and universal coverage of GPS technology gives it a great advantage over other high infrastructure cost locating solutions. GPS can be incorporated with wireless technology and sensors to allow earlier notification of injury, which means shorter response time. Dr. Schlager says, "The sooner rescue services can initiate treatment and

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[32] Steffy, Christina, "ITS to the Rescue," ITS World, July/August 1997, page 21

[33] Steffy, Christina, "ITS to the Rescue," ITS world, July/August 1997, page 22

[34] Steffy, Christina, "ITS to the Rescue," ITS world, July/August 1997, page 23

[35] Steffy, Christina, "ITS to the Rescue," ITS world, July/August 1997, page 23

[36] "Differential GPS and California's Disasters," Government Technology (Internet).

[37] Schlager, Dan, "The Global Positioning System and its emerging role in injury prevention."

[38] Schlager, Dan, "The Global Positioning System and its emerging role in injury prevention."

deliver these patients to an emergency department, the better the patients' chance of survival. The "golden hour of trauma" is a phase used to refer to the first hour after a traumatic injury is sustained. Injured persons delivered to an emergency department during this period have the best chance of survival."[39]

56% of all fatal accidents occur on rural roads, with only 11% of these fatalities occurring on interstates. DGPS will provide a method to achieve timely responses in cases of emergency. The response time interval for accidents in rural areas are significantly higher than they are for accidents in urban areas.[40]

7.3.5.3 Infrastructure Management on Highways

Several State Highway Departments use GPS to locate signs for inventory and maintenance purposes. DGPS would allow agencies to locate their signs with better accuracy, and thus improve maintenance efficiency and reduce costs. Minnesota Department of Transportation (MNDOT) already uses post-processing DGPS in surveying bridges, traffic signs and other structures along highways. Other anticipated GPS/DGPS applications include identifying property boundaries e.g., right-of-way and guardrails. MNDOT plans every three (3) years to collect points every 50' along all the centerlines of 12,000 miles of roads within the state. This translates to over 420,000 points every year. They require an accuracy of one (1) meter. They also must collect location data for right-of-way markers and road alignment points (some 50,000 points requiring centimeter accuracy), and road signs (100,000 at least). These points don't need to be collected every year obviously but do as new points are established or roads are built/rebuilt. Finally; MNDOT collects (needs to collect) points for 278,000 public land survey corners (plus a few thousand extra geodetic control monuments).

In Montana, the planning department for the Department of Transportation is in a three-year cycle to inventory the road systems as required to comply with federal highway regulations. Mile post offset monitoring is presently used for these inventories. DGPS was mentioned as a much better option. It would reduce the three-year cycle and improve utilization of manpower. Montana also discussed compliance with the federal regulations under ISTEA; such as studies of traffic flow past sites and the average speed. DGPS was discussed as an option for locating information equipment. Montana is also plotting all railroad-crossing locations and is building an image map for the 26,000 miles of highways. Their goal is to tie an image to the map every 10 meters.

The Virginia Department of Transportation (VDOT) uses DGPS and GIS to inventory the states highway structures e.g., cantilever signs, bridge-mounted signs, high-mast lights, etc. VDOT will use the database for maintenance/repair purposes. For data collection, VDOT prefers using real-time DGPS but may occasionally use post processing. A contact at VDOT staed that the principal benefits of using DGPS is the accuracy of the location data. He also surmised that a crew would save about ten (10) minutes locating a structure using real-time DGPS. VDOT has a goal to have statewide DGPS coverage. The VDOT contact mentioned other uses of DGPS including: AVL for snowplows, tracking hazardous waste (vehicles and sites) and mapping wetland boundaries.

7.3.5.4 Commercial Fleet Management

According to the USGIC, GPS based fleet management systems should reach $850 million in sales by the year 2000 while GPS based in-vehicle navigation systems sales are estimated to exceed $1 billion by the year 2000.

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[39] Schlager, Dan, "The Global Positioning System and its emerging role in injury prevention."

[40] Mitretek Systems, Key Findings from the Intelligent Transportation Systems (ITS) Program: What Have We Learned?, Federal Highway Administration, Washington, D.C., September 1996.

Freight and fleet management can provide the following benefits:

- Efficient dispatching through real-time monitoring and on-line communication
- Avoidance of misdirected, unnecessary, and no-load trips
- Assurance of just-in-time deliveries
- Hazardous materials transports can be guided along fixed routes. Any deviation is noticed immediately. Freight information and vehicle data are on-line and can be retrieved.

Use of advanced vehicle monitoring and communications technologies by motor carriers has demonstrated considerable time savings for commercial vehicle operators.[41] Schneider of Green Bay, WN reported a 20% increase in load miles. Trans-Western Ltd. Of Lerner, CO credits their fleet management system for improved driver relations, noting that drivers are able to drive 50 to 100 additional miles per day. Frederick Transport of Dundas, Ontario, Canada, estimates an increase of 20% in load miles, a reduction of $30 to $150 per month in telephone charges, a 0.7% greater load factor, and a 9% increase in total miles. Best Line of Minneapolis, MN estimates a $10,000 per month savings since 300 drivers previously lost about 15 minutes each day waiting to talk with dispatchers.

7.4 Benefits Estimates

7.4.1 DGPS Market/Application Areas Investigated

Because the magnitude of public and private markets where DGPS technology may be utilized is large as well as varied, it was not possible to estimate net benefits for all market areas. Instead, this benefits analysis has been focused on a number of key DGPS markets for which data was readily available. The following market and/or application areas are included in the analysis as well as "how" GPS/DGPS technology enables these applications to realize benefits:

US Railroad Industry **-** The goal of providing for Positive Train Separation (PTS) is embodied in one of the "Most Wanted" safety recommendations of the NTSB. The key to PTS is knowing accurately the location of trains so that a safe braking distance is maintained between trains. FRA positioning accuracy requirement is better than five (5) meters. There are a number of options available for selection of a primary Locations Determination System (LDS) but GPS/DGPS is the most economical option. The suitability of GPS/DGPS for PTS/PTC is best stated by FRA "...full deployment of U.S. Coast Guard differential GPS can significantly aid the development of positive train control systems by providing an affordable and competent location determination system that is available to surface and marine transportation throughout the contiguous United States."[42]

Highway Applications **-** As previously discussed, several highway applications, e.g., transit, emergency response, Mayday, infrastructure management on highways and commercial fleet management, require using a Location Determination System (LDS). Several LDS systems are in use to determine location. One of these LDS systems is GPS technology. The advantage of GPS technology is its nationwide (actually

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[41] Hallowell, S., and Morlok, E., "Estimation Cost Savings from Advanced Vehicle Monitoring and Telecommunicating Systems in Intercity Irregular Route Trucking, " Department of Systems, University of Pennsylvania, Philadelphia, PA, January 1992.

[42] "Differential GPS: An Aid to Positive Train Control:, Report to the Committees on Appropriations by FRA, June 1995, page ii.

worldwide) availability free of charge to the end user except for the hardware necessary to receive the GPS signal. This attribute made GPS attractive for many users who need a LDS system that is available over a wide geographical area. One of the ideal uses is highway applications since they span over large geographical areas and cross multiple jurisdictions. A USDOT publication[43] reported that 82 AVL systems of 105 systems utilize GPS. GPS/DGPS is used as a location determination system which is the intended use of GPS. Transit authorities and commercial fleet management equip their motor vehicles with GPS/DGPS receivers to identify their locations.

US Forest Service **-** Wild fire management is a big problem in the western states. The extensive wild fires in these states and the large costs of the property destroyed make firefighting a high priority. Aerial firefighting proved its effectiveness in wild fire mitigation. An important aspect of aerial firefighting is identifying location of fire retardant drops to avoid unnecessary overlap of retardant drops over the same area. GPS/DGPS is a well suited technology for this application since no geographic landmarks are necessary to identify location. GPS/DGPS technology enables fire tanker aircraft to drop fire retardant mixture efficiently. Using real-time DGPS for controlling retardant drops and target efficiency will result in 10% savings of retardant mixture. Moreover, GPS/DGPS technology enables both ground and air firefighters to communicate their locations accurately.

EPA Regional Offices **-** The nature of the EPA work requires identifying accurate location of water wells, hazardous sites, spill sites and storage facilities of contaminated materials. It is the EPA stated goal to get a location accuracy of 25 meters. However, several EPA personnel interviewed stated that location accuracy requirement depends on the application and that the 25 meter accuracy is not good enough. To achieve better accuracy, several EPA regional offices use “post-processing” DGPS technique to achieve accurate location data points. The term “post-processing” refers to the process were data is collected in the field using GPS receiver then using a computer program that has DGPS points for the same time and approximate location to calculate the differential for the surveyed locations. This technique requires several hours of processing data. The NDGPS, which will provide real-time differential corrections, will enable EPA staff to achieve the differential correction in the field, thus eliminating the need for “post-processing.” Several current users of DGPS stated that real-time DGPS saves, on average, fifteen (15) minutes per site surveyed over post-processing DGPS. This figure (15 minutes) is used to calculate EPA benefits attributed to the NDGPS Service in areas currently not covered by the USCG DGPS system.

Selected State/Local Agencies/Activities **-** Several state agencies, e.g., DOT and Pollution Control Agencies (PCA), need to collect location data of buildings, road signs and land boundaries. In general, state agencies use GPS/DGPS technology for positioning and surveying. For example, Minnesota DOT uses this technology to collect position data points for right-of-way markers, road signs and public land boarders. The MN health department uses the technology to locate water wells both public and domestic wells and any new wells added over time. The MN PCA uses GPS/DGPS to locate tanks and spills as well as water monitoring stations. The MN agriculture department uses GPS/DGPS to locate contaminant sources, spill sites and monitoring wells. GPS/DGPS enables these agencies to get three dimensional data points. The advantage of this technology is time saving, accuracy and universal reference point. State agencies calculated benefits are based on fifteen minutes (15)[44] time saving using real-time DGPS verses post-processing DGPS.

Agriculture **-** Use of DGPS is an inherent capability or enabling technology that is required to conduct “precision farming.” “Precision Farming” also known as “Precision Agriculture” or “site-specific

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[43] “Advanced Public Transportation Systems Deployment in the United States,” by Office of Research and Analysis, John A. Volpe National Transportation Systems Center, RSPA, USDOT, August, 1996.

[44] This figure was recommended by actual users interviewed for this study.

management" is the control of chemicals, fertilizers, and seeds to achieve the greatest output per acre per amount of input. In its simplest form, precision agriculture would be adding a little extra fertilizer to a few spots in the field that need a little extra or maybe leaving that back corner out that never did produce enough to pay for itself. On the other hand, precision agriculture could be the use of DGPS and powerful computer programs to map and apply customized amounts of seed, fertilizer, and chemicals to a field according to the need of each location.[45] It could also be the use of DGPS for yield monitoring which is basically tracking yield variance by geographic areas. Precision farming can provides substantial commercial benefits to farmers, as well as social benefits to the environment, in the form of a reduced application of harmful pesticides and herbicides, as well a more prudent use of fertilizer.

To the extent that favorable benefit-cost ratios can be demonstrated for just these limited number of applications, other applications not covered by the quantitative analysis would simply improve the overall benefit rating of the proposed service. Other potential economic and social beneficiaries of a ubiquitous DGPS service would include: USDOJ, US DOTres., US Postal Service, USDOT, NTSB, DOC, National Park Service, Federal, State and Local Emergency Management Agencies and State and Local Law Enforcement Agencies.

It should be noted that this quantitative analysis does not consider the potential benefits associated with service redundancy within the geographic areas covered by the existing USCG/ACOE systems. Here again, these benefits, which could be substantial, would increase the benefit-cost ratio over and above that estimated just for the four benefit categories listed above.

7.4.2 General Assumptions

The following general assumptions have been made.

As noted previously, the benefits analysis is confined to selected DGPS applications only in those areas currently *not* covered by the USCG/ACOE system. The benefit of adding redundancy within existing service coverage areas is not considered.

The benefits of DGPS are limited to a 15-year period, which is from 1999 to 2014. After that period, differential corrections may not be required inasmuch as Federal policy to terminate the use of SA should have been effectuated after that time. In addition, it is assumed that full realization of benefits will not occur immediately upon implementation of the proposed service. Instead, benefits are assumed to accrue over time, as information about DGPS is disseminated and as planning and investment requirements are gradually satisfied.

The USCG/ACOE systems and any similar system that may be added is intended to be used only for surface applications. The WAAS system, currently under development by the FAA, will be used for air navigation and traffic control purposes. WAAS does not represent a fully satisfactory alternative to the USCG/ACOE system for surface applications (see "Geostationary Satellite Coverage" white paper in the Appendix).

An assumption is made that generally it will take at least two years after the start of implementation of a nationwide DGPS service before users will realize any significant benefits from a universal DGPS service. This assumption is predicated on the belief that the DGPS service expansion will be a phased implementation as well as the fact that users will require a period of time to become aware of DGPS service availability and to acquire any additional enabling technology in order to utilize the service. Therefore,

[45] "Precision Agriculture - Farming for the Future," NCSU web site.

zero economic benefits are assumed for the first two years after providing service availability in those geographical areas currently not covered by the USCG/ACOE DGPS service.

Additional assumptions specific to the individual market categories are detailed in the respective sections below.

7.4.3 Railroad Industry: PTS/PTC

The Railroad industry has a potential to save millions of dollars every year once DGPS is available to support the implementation of Positive Train Separation (PTS) and positive train control (PTC). Jim Hall, the National Transportation Safety Board (NTSB) chairman, reported in a public hearing on June 26, 1996 that "Since January 1, 1996, the Railroad Division has launched [investigations] on 35 railroad accidents resulting in: 26 fatalities, 438 injuries and, over $60 million dollars in damages." Mr. Hall goes on to say "Train accidents that took place [he lists seven accident locations] could have been prevented if a fully developed positive train separation system had been in place. And now we must add other accidents to the list."

7.4.3.1 Approach and Methodology

The following assumptions are used in estimating the net benefits realized from the Nationwide DGPS Service:

- In the absence of nationwide DGPS coverage, PTS/PTC will not be widely implemented in the railroad industry, since 99.9% national coverage in a single frequency band is needed. This level of service cannot be provided in the absence of the proposed system, except through the use of a more expensive "transponder" technology. "Overall cost for a transponder-based location determination system applied to the U.S. main line rail system would be slightly greater than $200 million."[46]

- Commercial DGPS service does not offer a suitable level of national coverage. Especially in the context of the required availability and integrity for PTS/PTC.

- Not all railroads will utilize DGPS for PTS/PTC because they do not carry enough traffic, or for other financial reasons. It is assumed that only the 18,000 locomotives[47] of Class I railroad company will likely implement PTS. However, it should be recognized that Class I[48] railroads is credited to 86.7%[49] of all railroads train-miles in 1996. Class I railroads will likely fully implement PTS/PTC. However, net benefits are assumed to "ramp up" over time in increments of 20% annually starting in the third year of a nationwide DGPS signal availability. This approach will account for the assumption that there will be an elapsed time period to implement other technology necessary for PTS/PTC as well as the fact that not all users will simultaneously utilize the DGPS Service. This scenario would likely only be altered by a

[46] FRA Report to the Committees on Appropriations "Differential GPS: An Aid to Positive Train Control," June 1995, page 5.

[47] National Transportation Statistics, 1995; page 43.

[48] The Surface Transportation Board defines U.S. Class I railroads as those with average annual operating revenues of $253.7 million or more. (Source: FRA's Web site under definitions)

[49] FRA reported in 1996 that Class I total train miles are 581,632,458 and total all railroads train miles are 670,923,960 miles. Hence, Class I train miles is 86.7% of all railroads miles. (Source: FRA's Web site, Table 36)

Federal regulatory mandate that Class I railroads must implement PTS/PTC by some date certain

- The cost to implement PTS/PTC using DGPS is assumed to be approximately $10,000 per locomotive**.**

- AAR estimated annual benefits of Positive Train Control (PTC) to be $52.9 millions.[50] It is important to note that property damage alone for 1996 (a more current figure than the AAR estimate) is estimated at $60 million and thus far property damages for 1997 exceeds $70 million.

- Only 86.7% of the estimated annual benefits ($52.9 millions) is used to calculate benefits because Class I rail is credited for 86.7% of the total annual rail mileage.

- Since it is very difficult to provide a meaningful operations and maintenance estimate for a system that has not been designed, an annual figure of 10% of capital cost has been selected. This figure is a general average for most sophisticated electronic systems.

7.4.3.2 Calculations

Using the previous assumptions, estimation of the annual net benefits realized from the implementation of PTS using DGPS is set forth below.

Annual Gross Benefits = (86.7% * 52.9 million) = $ 45.86 million

PTS Implementation Cost for Class I Railroad Locomotives = 18,000 locomotives * $10,000/locomotive

= $180 million

Annual Net Benefit for each year of the system life cycle is shown in Table 6 below.

Table 6. Estimated Railroad Industry Potential Benefits

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	$0.00	$0.00	$0.00	$0.00
2	$0.00	$0.00	$0.00	$0.00
3	$36.00	$3.60	$9.17	-$30.43
4	$36.00	$7.20	$18.35	-$24.85
5	$36.00	$10.80	$27.52	-$19.28
6	$36.00	$14.40	$36.69	-$13.71
7	$36.00	$18.00	$45.86	-$8.14
8	$0.00	$18.00	$45.86	$27.86
9 to 15	$0.00	$126.00	$321.05	$195.05
Total	**$180.00**	**$198.00**	**$504.51**	**$126.51**

[50] FRA's Report to Congress "Railroad Communications and Train Control," July 1994, page 58.

7.4.4 Highway Applications

GPS/DGPS is becoming part of several highway applications. Highway applications include transit systems, mayday and emergency response, infrastructure management on highways and commercial fleet management. GPS/DGPS based AVL systems are preferred among transit authorities and commercial fleet management. A unique advantage of a GPS based AVL system is, that it works anywhere on earth. Main highway applications that have public safety benefits are mayday and emergency response. GPS/DGPS enables rescuers to locate victims in a shorter time. It is estimated that GPS/DGPS will save 3% of the 41,000 lives lost on highways through faster response[51]. To realize these benefits, emergency service providers, i.e., police, fire departments and rescue squads, need to implement a GPS-based AVL system. A more conservative figure to use in calculating benefits is 1.5%. Inasmuch as many municipal and county governments as well as volunteer fire departments and rescue squads may not have the resources to procure the necessary equipment to implement a DGPS based AVL system.

7.4.4.1 Approach and Methodology

Benefits of a Nationwide DGPS service in highway applications are very hard to quantify. It is easiest to quantify public-safety benefits realized from potential life savings. The following assumptions are used:

- The Nationwide DGPS has the potential to save at least 1.5% of the 41,000 lives lost annually on highways simply be expediting rescue efforts.

- USDOT value for human life is $ 2.7 million.

- It is assumed that 20,000 emergency response entity e.g., police, sheriff, rescue and fire departments will likely implement a DGPS-based AVL system.

- Each emergency response entity will install AVL equipment in five (5) vehicles as well as a Computer Aided Dispatch (CAD) center.

- Cost to equip a vehicle with AVL is estimated to be $3,000 per vehicle and the cost to equip a CAD center with AVL is estimated to be $30,000.

- Existing radio communications will be used.

- Benefits will “ramp up” over ten year period starting in the third year of a nationwide DGPS signal availability. The rational for this assumption is that the life cycle for emergency equipment and electronics in municipalities is about ten (10) years and not all municipalities will have the resources to build an AVL system.

- Since it is very difficult to provide a meaningful operations and maintenance estimate for a system that has not been designed, an annual figure of 10% of capital cost has been selected. This figure is a general average for most sophisticated electronic systems.

7.4.4.2 Calculations

Potential lives saved annually = 41,000 lives/year * 1.5% = 615 lives

Gross life saving benefits ($) = Number of lives saved * $ 2.7 million = 615 * $ 2.7 millions

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[51] NHTSA is currently conducting a study of the lives that may be saved through the usie of more efficent and timely emergency response methods. The report is expected to be completed by 3Q98.

= $ 1,660,500,000 (1.66 billions)

Capital cost to install AVL systems in a CAD center = 20,000 * $30,000 = $ 600,000,000 (600 million)

Capital cost to equip vehicles with AVL = 20,000 * 5 vehicles/entity * $ 3,000 = $ 300 million

Total Capital investment in AVL = $ 600 M + $ 300 M = $ 900 M

Annual net Benefit for each year of the system life cycle is shown in Table 7 below.

Table 7. Estimated Highway Applications Potential Benefits

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	$0.00	$0.00	$0.00	$0.00
2	$0.00	$0.00	$0.00	$0.00
3	$90.00	$9.00	$166.05	$67.05
4	$90.00	$18.00	$332.10	$224.10
5	$90.00	$27.00	$498.15	$381.15
6	$90.00	$36.00	$664.20	$538.20
7	$90.00	$45.00	$830.25	$695.25
8	$90.00	$54.00	$996.30	$852.30
9	$90.00	$63.00	$1,162.35	$1,009.35
10	$90.00	$72.00	$1,328.40	$1,166.40
11	$90.00	$81.00	$1,494.45	$1,323.45
12	$90.00	$90.00	$1,660.50	$1,480.50
13 to 15	$0.00	$360	$4,981.50	$4,621.50
Total	**$900**	**$855.00**	**$14,114.25**	**$12,359.25**

7.4.5 U.S. Forest Service Cost Savings

In 1996 the U.S. Forest Service fought a wild fire in Idyllwild CA that resulted in heavy use of firefighting assets including the use of several DC-4 fire tanker aircraft.

Based upon the known data for this event, a theoretical aerial firefighting scenario can be constructed using real-time differential corrections, a GIS database(s) and digital maps such that command and control of aerial firefighting aircraft will produce a more effective fire mitigation plan that will deploy more efficiently the manpower and aircraft resources.

Using this event as a typical case, the US Forest Service actively provides aerial fire fighting services and contracts to outside commercial air service providers. The costs of a portion of these services are distributed as follows [Reference: US Department of Forestry -Aviation sources]:

- DC-4 aerial tankers with two pilot crews are utilized
- Each aircraft carries one 2,000 gallon capacity tank containing a fire retardant mixture that is priced at 80 cents per gallon and which totals $1,600 per tank full
- Aircraft duty cycles are eight hours of flight time per day plus any ground time.

- An aircraft averages two aerial missions per hour (or 16 sorties during one twelve hour period)

Agency staff estimated that utilizing real-time DGPS corrections over conventional targeting methods will produce better results which will lead to a reduction in the use of payload materials as well as the number of aircraft sorties required.

Using actual payload retardant cost, it is estimated that one aircraft flying 16 sorties (drop missions) using real-time DGPS for controlling retardant drops and target efficiency (payload management) will gain an improvement of 10% which would result in a savings of $2,560 per aircraft per day ($1600 * 16 = $25,600 * 10% = $2,560).

In the case of the 1996 class B Idyllwild, CA fire, five DC-4 aircraft were deployed over several days of the fire. In this instance, using DGPS, the cost savings in payload management efficiencies gained for a “single” day of that fire would have been $12,800 ($2,560 * 5 = $12,800/day).

During 1994 and 1996 fire years (data was not available for 1995), Federal wildland firefighting agencies in the Department of the Interior and Agriculture spent upwards of $100 million per year on aircraft costs [BLM Fire & Aviation estimates]. Of this cost, the majority is spent in a 100-day wildland fire season (June through August) for an average expenditure of $1,000,000 per day.

Note: An operational test is under development in a cooperative agreement between BLM and NASA-Ames that will involve an aircraft utilizing a DGPS-based cockpit GIS/digital map system with a communication link to ground forces.

7.4.5.1 Approach and Methodology

The US Forest Service benefits are calculated using the class B Idyllwild fire as a typical case involving the use of aerial firefighting, by utilizing DGPS technology in support of aerial firefighting operations and making the following assumptions:

- The use of DGPS will improve efficiency by 10%, which will save $12,800 per day during the firefighting season.

- An assumption is made that it costs $20,000 to equip an aircraft with the necessary hardware to utilize the DGPS Service.

- Annual 100-day firefighting season is assumed.

- Benefits are assumed to "ramp-up" over time since not all users will implement the DGPS service simultaneously. To account for this assumption, benefits will start with 20% in the third year of the system life cycle.

- Some firefighters will likely utilize GPS augmentation methods other than a USCG-type DGPS service in their operations. To account for this assumption, only 50% of benefits will be considered.

- No benefits have been attributed to faster fire mitigation, which may save lives, property and natural resources.

- Since it is very difficult to provide a meaningful operations and maintenance estimate for a system that has not been designed, an annual figure of 10% of capital cost has been selected. This figure is a general average for most sophisticated electronic systems.

7.4.5.2 Calculations

Annual gross benefits = Daily savings * Number of days per firefighting season * 50%

= $12,800/day * 100 days * 50%

= $ 640,000

Table 8 below shows estimated potential benefits for each year of the system's life cycle.

Table 8. Estimated U.S. Forest Service Potential Benefits

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
3	0.020	0.002	0.128	0.106
4	0.020	0.004	0.256	0.232
5	0.020	0.006	0.384	0.358
6	0.020	0.008	0.512	0.484
7	0.020	0.010	0.640	0.610
8	0.000	0.010	0.640	0.630
9 to 15	0.000	0.070	4.480	4.410
Total	**0.100**	**0.110**	**7.040**	**6.830**

7.4.6 EPA Regional Offices, "Point Source" Sampling/Data Collection

7.4.6.1 Approach and Methodology

The approach taken here in calculating benefits to the EPA accounts for potential benefits realized from using real-time DGPS vs. post processing techniques. All data points used to calculate the benefits were obtained from EPA regional offices. The following assumptions are made:

- Any benefits to be realized from the use of DGPS include only the limited incremental benefits that would be realized by upgrading work methods from post-processing to the use of real-time DGPS. They do not include the broader benefits that would be realized by upgrading from traditional surveying methods to the use of real-time DGPS.

- Only areas currently not covered by USCG/ACOE DGPS are included in the benefit calculations.

- Benefits realized from utilizing DGPS for navigation purposes are not included.

- The calculated benefits do not account for the increase of signal reliability in covered areas under the existing USCG/ACOE systems.

- The calculations assume one visit per site even though multiple visits to the same site may be necessary.

- Fifteen (15) minutes of time saving per site is used which is a conservative figure since some users reported time saving of thirty (30) minutes per site.

- Net benefits are assumed to "ramp up" over time. Benefits are incremented for five (5) years at 20% each year starting in the second year of the system life cycle. This accounts for the assumption that not all users will initially utilize the DGPS service instantaneously.

- A loaded hourly wage of $50 is used.

- Five EPA regions estimate buying 23 new GPS/DGPS receivers within the first (5) years of the project to utilize the real-time DGPS service. An assumption is made that the rest of the EPA regions will buy 27 GPS/DGPS receivers as well.

- An average cost of $5,000 per receiver is used.

- Only 50% of all points surveyed by EPA will realize (benefit from) the proposed DGPS service since some EPA groups may be happy with other existing methods and accuracy and will not utilize DGPS technical methods.

- Since it is very difficult to provide a meaningful operations and maintenance estimate for a system that has not been designed, an annual figure of 10% of capital cost has been selected. This figure is a general average for most sophisticated electronic systems.

7.4.6.2 Calculations

The EPA estimated visiting (locating) over 300,000 points (sites) annually. Currently 137,199 points of the 300,000 points are not covered by the USCG/ACOE DGPS system. Applying (15) minutes savings per point and a $50 hourly wage, the benefit calculations are shown below:

Annual Gross Benefits = 137,199 points currently without DGPS * [(15 minutes saved/point)/(60 minute/hour)] * $50/hour * 50% = $ 857,493

It is estimated that the EPA will buy 50 new GPS/DGPS receivers within the next 5 years at an average cost of $ 5,000 per receiver in order to obtain benefits from the DGPS service.

User Cost for the first (5) years = 50 receivers X $ 5,000/receiver = $ 250,000

Table 9 below summarizes the capital cost, annual O&M cost, gross benefits and net benefits for every year of the system life cycle.

Table 9. Summary of Estimated Potential EPA Cost and Benefits

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	$0.000	$0.000	$0.000	$0.000
2	$0.000	$0.000	$0.000	$0.000
3	$0.050	$0.005	$0.171	$0.116
4	$0.050	$0.010	$0.343	$0.283
5	$0.050	$0.015	$0.514	$0.449
6	$0.050	$0.020	$0.686	$0.616
7	$0.050	$0.025	$0.857	$0.782
8	$0.000	$0.025	$0.857	$0.832
9 to 15	$0.000	$0.175	$6.00	$5.83
Total	**$0.250**	**$0.275**	**$9.432**	**$8.907**

7.4.7 State Agency Cost Savings from Real-Time DGPS Processing

7.4.7.1 Approach and Methodology

In this category of benefits, it was impossible to collect data from all states for various reasons. A few states are currently active in planning the implementation of statewide DGPS service, as is the case in Texas and Minnesota. Other states are using DGPS on a smaller. The state of Minnesota was chosen as a model state (because DGPS usage information is available). The study group extrapolated the benefits, based on state population to all other states. This approach relied on the following assumptions:

- Only four state agencies usage are accounted for in the benefits because these are the agencies which provided data. In reality, several other agencies will likely benefit from the system.
- Only areas currently not covered by USCG/ACOE DGPS system are included in the calculations.
- The benefits account for time saving from using real-time DGPS vs. post processing only.
- Benefits do not include the use of real-time DGPS vs. conventional methods of surveying.
- Benefits (time saving) realized from utilizing DGPS for navigation purposes are not included.
- The calculated benefits do not account for the increase of signal reliability in areas covered under the existing system.
- Fifteen (15) minutes of time saving per site is used even though figures as high as thirty (30) minutes has been reported.
- Net benefits are assumed to "ramp up" over time. Using increments of 20%, starting in the third year of the system life cycle, will account for this assumption since not all users will utilize the DGPS service simultaneously.
- A loaded hourly wage of $40 is used.
- The State of Minnesota estimates buying 100 new GPS/DGPS receivers within the first (5) years of the project to utilize the real-time DGPS service.

- An average cost of $5,000 per receiver is applied.

- Net benefits are extrapolated to other states based on population.

- Only 50% of all points surveyed will utilize the proposed DGPS Service since some users may feel comfortable with using other surveying methods.

- Since it is very difficult to provide a meaningful operations and maintenance estimate for a system that has not been designed, an annual figure of 10% of capital cost has been selected. This figure is a general average for most sophisticated electronic systems.

7.4.7.2 Calculations

Calculations are conducted in two steps. The first step is to calculate the State of Minnesota's net benefits and the second step is to extrapolate these savings, based on population, to all other states.

State of Minnesota:

Total number of points visited annually = 494,100 points

Potential Gross Benefits = 494,100 points * [(15 minutes/point)/(60 minutes/hour)] * $40/hour * 50% implementation percentage * 0.4 of state currently not covered by USCG/ACOE DGPS

= $ 988,200

Annual User Cost for the first (5) years = 100 receivers * $ 5,000/receiver = $ 500,000

Annual Net Benefit for the first (5) years =(Annual Gross Benefit - Annual User Cost - Annual O&M cost)

= ($ 988,200 - $ 100,000 - $10,000) = $ 878,200

All subsequent years will show annual net benefits of $938,200 ($ 988,200 - $ 500,000 * 10%).

All other States:

The state of Minnesota benefits and costs are extrapolated, based on population and accounting for areas currently not covered by the USCG/ACOE DGPS system, to other states.

Table 10 below lists net benefits per year realized by parts of states currently without DGPS coverage.

Table 10. Summary of Estimated Potential Net Benefits for Parts of States Currently without DGPS Coverage

Year	Capital Cost ($ M)	Annual O&M ($ M)	Gross Benefits ($ M)	Net Benefits ($ M)
1	$0.00	$0.00	$0.00	$0.00
2	$0.00	$0.00	$0.00	$0.00
3	$0.96	$0.10	$4.73	$3.68
4	$0.96	$0.19	$9.46	$8.31
5	$0.96	$0.29	$14.19	$12.95
6	$0.96	$0.38	$18.93	$17.58
7	$0.96	$0.48	$23.66	$22.22
8	$0.00	$0.48	$23.66	$23.18
9 to 15	$0.00	$3.35	$165.60	$162.24
Total	**$4.79**	**$5.27**	**$260.22**	**$250.17**

7.4.8 Agriculture

Agriculture is a major sector that will benefit from a nationwide DGPS service. Precision farming utilizes DGPS for both navigation and location identification during the application of fertilizers, herbicides and pesticides. Precision farming methods enable farmers to control the quantity of fertilizer and pesticide distributed on different areas of land depending upon soil type and other factors. Contacts have reported substantial savings on fertilizer and pesticides/herbicides as well as improved crop yields using precision farming techniques. One farmer reported an $80,000 annual saving from a 6,000-acre farm.

The Natural Resources Conservation Service (NRCS) within the US Department of Agriculture advocates using a $5 per acre net benefit for cultivable cropland since a more detailed study would be required to certify the greater benefits ($14 per acre) that have been reported by some farmers. NRCS recommends using the 1992 National Resource Inventory (NRI) crop land figures to establish the magnitude of cultivable crop land. The 1992 inventory shows 382 million acres nationwide.

It should also be recognized that commercial DGPS service is currently available in much of the geographical areas not presently covered by the USCG/ACOE service. The magnitude of subscription to this “fee-for-use” service is unknown. However, because the implementation of precision farming techniques is still rather limited (≤ 9%) in the geographical areas under consideration, it would not seem that DGPS fee-for-use technology has yet to substantially penetrate the agricultural market.

7.4.8.1 Approach and Methodology

To provide an accurate estimate of potential benefits, the following methodology and assumptions are used:

- The 1992 crop land acres are used for each state rather than total farm acres since many farms are used only for grazing and are not cultivated.
- Only those portions (percentage) of states NOT currently covered by USCG/ACOE service are used in calculating benefits
- Net saving of $5 per acre is used in calculating benefits. This figure presumes that capital cost to farmers and annual O&M costs have been accounted for.

- Not all farmers will utilize DGPS. Only farmers with large crop land farms ($\geq$1000 acres) or major cooperatives will likely utilize DGPS for precision farming. Therefore, market penetration has been set at 50% of all crop land for purposes of the benefits estimate.

Note[52]: DGPS is an enabling technology for site-specific farm management. However, precision agriculture is not one thing, but a group of technologies applied to different production tasks. Key elements in precision agriculture are:

- Geographic information system (GIS) and mapping software
- Yield monitors and mapping systems
- Variable dispensing-rate technologies
- Low-volume irrigation
- Grid soil sampling
- Ground-based sensors and remote sensing
- Crop quality and quantity production modeling software

And decision support systems.

- Net benefits are assumed to "ramp up" over time in increments of 20% starting in the third year of universal DGPS signal availability. This approach will account for the assumption that there will be an elapsed time period to implement other technology necessary for precision farming as well as the fact that not all users will simultaneously utilize the DGPS Service.

7.4.8.2 Calculations

The National Resource Inventory (NRI) reported in 1992 that there are 382 million acres of crop land in the United States. Of these crop land acres, 124.947 million acres currently are not covered by the USCG/ACOE DGPS system. The calculations below show potential benefits realized by precision farming from the proposed system.

Annual Net Benefits = Net Benefit per acre * Number. of acres currently without DGPS Coverage * 50% Market Penetration = $5/acre * 124,947,120 acres * 50% = $ 312,367,800

Starting in the third year, 20% of the potential annual net benefit will be used and after the sixth year 100% of net benefits will be used for the remaining life cycle of the proposed service. Table 11 below shows estimated potential benefits for each year of the system life cycle.

[52] GPS World Newsletter, September 12, 1997

Table 11. Estimated Agriculture Potential Benefits

Year	Net Benefits ($ M)
1	$ 0.0
2	$ 0.0
3	$ 62.47
4	$ 124.95
5	$ 187.42
6	$ 249.89
7	$ 312.37
8 to 15	$ 2,498.94
Total	**$ 3,436.06**

7.5 Fifteen Year Benefit-Cost Comparison

Consistent with requirements of Office of Management and Budget (OMB) Circular A-94, the DGPS Policy and Implementation Team looked at a number of relevant benefits. The ever increasing number of DGPS applications makes it nearly impossible to capture all of the benefits but in the five months that the DGPS Policy and Implementation Team spent researching the benefits issue it has identified enormous savings both in terms of lives saved and improved efficiencies. The net present value of benefits over the 15 year life cycle has been divided into two categories:

- **<u>Public Safety Related Benefits</u>**

  This group of benefits include the following entities:

  - Railroad Industry
  - Highway Applications
  - US Forest Service
  - EPA Regional Offices

- **<u>Non Public Safety Related Benefits</u>**

  This group of benefits include the following entities:

  - State/Municipal/Local Government Agencies
  - Agriculture Industry

Using the OMB Circular A-94 method of determining life cycle benefits, the net present value over the 15 year life cycle for the Nationwide DGPS Service is over $10 billion.

The capital cost to complete nationwide coverage of an LF/MF Radiobeacon DGPS signal is estimated to be between $28.62 million and $37.62 million, depending on which of three options is used. The two lower cost opportunities involve taking advantage of US Air Force (USAF) plans to decommission its Ground Wave Emergency Network (GWEN) late in FY 1998. These two options save the USAF some of the costs associated with decommissioning the GWEN system while also decreasing USDOT cost to install the Nationwide DGPS. Annual operating and maintenance costs for the sites necessary to complete nationwide coverage are expected to be approximately $4.66 million. Thus, again using OMB Circular A-94 method of determining life cycle costs, the net present value over the 15 year life cycle of the Nationwide DGPS service is only $68.63 million.

Table 11 illustrates the overall monetary benefits and savings associated with implementing the Nationwide DGPS service.

Consistent with OMB Circular A-94 guidelines, a 7% discount rate is applied to “external” benefits while a 3.525% discount rate (for a 15-year life cycle) is applied to Federal government benefits. Only the agriculture benefits are considered “external” benefits since other benefits accounted for in this report are incurred either directly or indirectly by the Federal government. Example of direct benefits are the EPA and US Forest Service, while examples of indirect benefits are the railroads and Highways.

Since the $10.44 billion life cycle benefits far outweigh the $68.63 million life cycle costs, the team strongly recommends that the Nationwide DGPS be implemented.

Table 12. Fifteen Year Life Cycle Net Present Value of The DGPS Service Net Benefits

	COST	Public Safety Benefits				Non Public Safety Benefits	
YEAR	NDGPS Cost (in Millions)	Railroad Industry Net Benefits (in Millions)	Highway Net Benefits (in Millions)	US Forest Net Benefits (in Millions)	EPA Net Benefits (in Millions)	States Net Benefits (in Millions)	Agriculture Net Benefits (in Millions)
1	$2.40	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2	$4.67	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3	$9.09	-$27.42	$60.43	$0.10	$0.10	$3.32	$51.00
4	$9.97	-$21.64	$195.10	$0.20	$0.25	$7.23	$95.32
5	$9.99	-$16.21	$320.53	$0.30	$0.38	$10.89	$133.63
6	$3.78	-$11.14	$437.19	$0.39	$0.50	$14.28	$166.52
7	$3.65	-$6.38	$545.54	$0.48	$0.61	$17.44	$194.53
8	$3.53	$21.12	$646.00	$0.48	$0.63	$17.57	$181.80
9	$3.41	$20.40	$738.98	$0.46	$0.61	$16.97	$169.91
10	$3.29	$19.71	$824.89	$0.45	$0.59	$16.39	$158.79
11	$3.18	$19.03	$904.09	$0.43	$0.57	$15.83	$148.40
12	$3.07	$18.39	$976.93	$0.42	$0.55	$15.30	$138.70
13	$2.97	$17.76	$943.67	$0.40	$0.53	$14.77	$129.62
14	$2.87	$17.16	$911.54	$0.39	$0.51	$14.27	$121.14
15	$2.77	$16.57	$880.50	$0.37	$0.49	$13.79	$113.22
Total	**$68.63**	**$67.34**	**$8,385.39**	**$4.86**	**$6.33**	**$178.05**	**$1,802.57**

15 Year Life Cycle CBA Summary		
	Total	***Ratio***
NPV of System Cost ($ M) =	***$68.63***	***1***
NPV of Public Safety related Benefits ($ M) =	***$8,463.92***	***123***
NPV of Non Public Safety related Benefits ($ M) =	***$1,980.62***	***29***
NPV of all Bnefits ($ M) =	***$10,444.54***	***152***

8. SUMMARY AND RECOMMENDATION

Essentially, the aim of the DGPS Policy and Implementation Team's investigation has been to revalidate the requirements identified in the 1994 Augmentation Study and then to reconcile the recommendations of the 1994 Augmentation Study with the policies set forth in the PDD.

This study affirmed users requirements collected for the 1994 Augmentation study as well as the findings of the GAO study published in September 1994. Many Federal and state agencies as well as certain major transportation industries have public or personal safety requirements; such as law enforcement officers, NPS, EPA, USPS, US Forest Service, the railroad industry; and public transit agencies. While numerous other agencies as well as industry sectors have non-public safety requirements such as NGS, USGS, DOA and the agriculture industry.

Many public safety applications that require DGPS have been found. These include Positive Train Separation (PTS), Search and Rescue (SAR), emergency 911 response, positioning navigational aids, law enforcement, natural resource monitoring, ground water contamination monitoring, hazardous material contamination abatement, and safety infrastructure location mapping. Each of these critical safety applications either saves lives directly, prevents loss of life, or reduces the chances for both near and long term public health risks.

The Team has concluded that the Nationwide DGPS service as presented in “A Technical Report to the Secretary of Transportation On A National Approach to Augmented GPS Services” in December 1994 is still required and is consistent with the direction the President gave in the PDD.

The Team also performed a cost benefit analysis in accordance with OMB Circular A-94. The net present value of benefits over the 15 year life cycle for the Nationwide DGPS Service is $10.44 billion.

Depending on the availability of the Air Force GWEN sites, service installation costs will be between $28.62 and $37.62 million with a 15 year life cycle costs of only $68.63 million.

Since the $10.44 billion benefits far outweigh the $68.63 million cost the DGPS Policy and Implementation Team believes that there are sufficient requirements as well as compelling social and economic benefits to justify providing a Nationwide DGPS Service. More importantly, there are significant public safety benefits to warrant immediate implementation of the Nationwide DGPS Service.

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APPENDIX A1: ACRONYMS LIST

The following is a listing of acronyms used in this report:

A

ACOE	United States Army Corps of Engineers
ATF	Bureau of Alcohol, Tobacco and Firearms
AVL	Automatic Vehicle Location

B

BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BOR	Bureau of Reclamation

C

CAD	Computer Aided Dispatch
CFR	Code of Federal Regulations
CONUS	Continental United States (contiguous 48 states)
CORS	Continously Operating Reference Station

D

DEA	Drug Enforcement Agency
DGPS	Differential Global Positioning System
DOA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOJ	Department of Justice
DOT	Department of Transportation

DOTres.	Department of Treasury
drms	Distance Root Mean Square

E

EPA	Environmental Protection Agency

F

FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FTCA	Federal Tort Claims Act
FY	Fiscal Year
FWS	Fish and Wildlife Service

G

GAO	General Accounting Office
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GLONASS	Global Orbiting Navigation Satellite System
GPS	Global Positioning System
GWEN	Ground Wave Emergency Network

H

I

IALA	International Association of Lighthouse Authorities
IMO	International Maritime Organization
IRC	Internal Revenue Code
ITS	Institute for Telecommunication Sciences
ITU	International Telecommunication Union

J

K

L

LAAS	Local Area Augmentation System
LF	Low Frequency

M

MF	Medium Frequency
MMS	Minerals Management Service

N

NGS	National Geodetic Survey
NPS	National Park Service
NRCS	National Resources Conservation Service
NRI	National Resource Inventory
NSTC	National Science and Technology Council
NTIA	National Telecommunication and Information Administration
NTSB	National Transportation Safety Board

O

OMB	Office of Management and Budget
OSM	Office of Surface Mining
OST	Office of the Secretary of Transportation

P

PCA	Pollution Control Agency
PDD	Presidential Decision Directive
PLGR	Precision Lightweight GPS Receiver
PPS	Precise Positioning Service
PSWAC	Public Safety Wireless Advisory Committee
PTC	Positive Train Control
PTS	Positive Train Seperation

Q

R

RINEX	Receiver Independent Exchange
RTCM	Radio Technical Commission for Maritime Services

S

SA	Selective Availability
SAR	Search and Rescue
SPS	Standard Positioning Service

T

U

US	United States

USAF	United States Air Force
USCG	United States Coast Guard
USFS	United States Forest Service
USGS	United States Geological Survey
USPS	United States Postal Service

V

VDOT	Virginia Department of Transportation
VHF	Very High Frequency
VSAT	Very Small Aperture Terminal

W

WAAS	Wide Area Augmentation System

APPENDIX A2: GLOSSARY OF TERM

Accuracy - The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position or velocity. Radionavigation system accuracy is usually presented as a statistical measure of system error and is specified as:

> Predictable—The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum.
>
> Repeatable—The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
>
> Relative—The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Availability - The availability of a navigation system is the percentage of time that the services of the system are usable. It is an indication of the ability of the system to provide usable service within the specified coverage area. It is important to realize that the term "availability" has different meanings for different systems. For example, the U.S. Coast Guard defines availability as the percentage of time in a one month period during which a DGPS Broadcast transmits healthy signal at its specified output level (e.g., exceeding 75 uV/m for 100 bps broadcast).

Category I (II, III) Landing - Designations for successively more-difficult classes of aircraft precision landings (with difficulty determined by visibility and weather conditions).

Class I Railroad - U.S. Class I railroads are those with average annual operating revenues of $253.7 million or more.

Continuously Operating Reference Station (CORS) - A group of GPS reference stations, coordinated by the National Geodetic Survey (NGS), NOAA, that will provide code range and carrier phase data to users in support of post-processing applications. NGS plans to establish very few GPS stations specifically to support the CORS system. Rather, use is being made of data from GPS stations established by other organizations to support their specific requirements, thus making the stations multi-use. The primary source of CORS system data will be GPS stations established and operated by components of the Department of Transportation to support real-time navigation and positioning. Currently, CORS network has 112 operational sites.

Coverage - The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

Differential - Technique to improve system accuracy by determining positioning errors of a known location (reference station) and subsequently broadcasting the positioning errors or corrective factors to users within the coverage area.

Distance Root Mean Square (drms) - The root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. As used in this document, 2 drms is the radius of a circle that contains at least 95 % of all possible fixes that can be obtained with a system at any one place. Actually, the percentage of fixes contained within 2 drms varies between approximately 95.5% and 98.2%, depending on the degree of ellipticity of the error distribution.

Dual-coverage - It connotes that signal i.e., DGPS signal from two independent radiobeacon stations are present within a coverage area. This is a method to increase system reliability.

FM Subcarrier - A method of disseminating differential correction by "piggy-backing" the differential correction data on commercial FM radio signals.

Global Navigation Satellite System (GNSS) - A generic term for an emerging satellite radionavigation system that provides global coverage; in current use, GNSS often refers to GPS, its augmentations and enhancements, and GLONASS.

Global Orbiting Navigation Satellite System (GLONASS) - The Russian equivalent to the American GPS satellite radionavigation system. It also provides global position, velocity, and timing service. GLOSASS has separate civil and military signals comparable in accuracy to those of GPS with SA turned to zero. GLONASS appears to have no selective Availability (SA) feature as the case in GPS.

Global Positioning System (GPS) - Satellite radionavigation system owned and operated by the US DoD. This system provides global position, velocity, and timing service. GPS has civil service known as SPS and a military service known as PPS. GPS has Selective Availability (SA) feature to degrade signal accuracy for civilian users.

Ground Wave Emergency Network (GWEN) - A communications system consisting of long towers similar to those used by commercial broadcasting station transmitters. GWEN was developed in the mid 80's as a communications medium in the case of nuclear attack during the cold war.

Integrity - Is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

Mapping - Conducting a survey for map making.

Navigation - Process of planning, recording, and controlling the movement of a craft, ship or vehicle from one point to another.

Positioning - Identifying the location of someone or something with respect to a reference point.

Positive Train Control (PTC) - The application of technology to control the movement of trains in a manner that precludes the occurrence of collisions.

Positive Train Separation (PTS) - The application of technology in various subsystems that intervene to prevent trains from operating at a speed in excess of the maximum allowed, movement past any point of known obstruction or hazard, and movement beyond the limits authorized.

Precise Positioning Service (PPS) - This is the military service of GPS. It is the more accurate service of both GPS services providing accuracy level of 21 meters at 95 percent probability.

Radionavigation - The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

Receiver Independent Exchange (RIENX) - Is a data format based upon a set of standard definitions for GPS observables (time, phase and range). Use of RINEX allows appropriate software to process RINEX formatted GPS data, even though it is collected using different vendor receivers. Most GPs manufacturers use their own proprietary formats for the data collected using their equipment. Before the advent of RINEX, users had no way of post-process GPS data collected using different vendor equipment, unless they had access to the restricted knowledge about the manufacturer's proprietary format. RINEX removes this restriction on the user by providing a standard format which can be used for the post-processing and analysis of GPS data.

Reliability - The probability of performing a specified function without failure under given conditions for a specified period of time.

Selective Availability (SA) - The method by which intentional errors in timing and positioning data are introduced, by the DOD, into civilian GPS signal known as SPS. SA currently degrades the accuracy of the SPS signal to approximately 100 meters (2 drms)

Single-Coverage - It connotes that signal i.e., DGPS signal from one radiobeacon station is present within a coverage area versus "dual-coverage" which connotes signals from two independent radiobeacon stations are available.

Standard Positioning Service (SPS) - This is the civilian service of GPS. It is the less accurate service of both GPS services providing accuracy level of 100 meters at 95 percent probability. This signal is open to all users nationwide.

Surveying - Measurement of dimensional relationships i.e., horizontal distances and elevations to locate property boundaries.

Tracking - Monitor the movement of someone or something by continuously knowing their location.

APPENDIX B1: RESULTS OF 1996 STUDY - FEDERAL AGENCIES' AND OTHER ORGANIZATIONS' APPLICATIONS OF DGPS

INFORMATION FROM 1996 USER SURVEY FOR L5		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
Bureau of Alcohol, Tobacco, and Firearms	POSITIONING AND NAVIGATION	<10 m
Bureau of Land Management	POSITIONING	<10 cm
Bureau of Land Management	MAPPING	<2 m
Bureau of Land Management	NAVIGATION	<5 m
Bureau of Land Management	SURVEYING	~ cm
Bureau of Land Management	SURVEYING (CONTROL)	<2 cm horiz, <15 cm vertical in terms of orthometric heights
Bureau of the Census, Geography Division	POSITIONING	<5 m horizontal
California Department of Forestry and Fire Protection	NAVIGATION AND POSITIONING	<10 m
Federal Communications Commission	POSITIONING	<5 m horiz, <5 m vertical
FHWA, US DOT	NAVIGATION	<15 m
FHWA, US DOT	MAPPING	<1 m
FHWA, US DOT	RESEARCH	<5 cm
General Services Administration	No Defined Requirement	No Defined Requirement
US Army Corps of Engineers	NAVIGATION	<10 m
US Army Corps of Engineers	NAVIGATION	<100 m
HQ, US Army Corps of Engineers	POSITIONING	<2 m to <5 m
IDAHO Division of Environmental Quality	POSITIONING	<5 m
Indiana Dunes National Lakeshore	POSITIONING	<3 m to <10 m

INFORMATION FROM 1996 USER SURVEY FOR L5		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
Long Distance Trails Office, Salt Lake City, UT	POSITIONING	<5m
MMS	POSITIONING	1 m > 10 m
NASA Goddard Space Flight Center		
NASA HQ Polar Research Program	POSITIONING	<1 cm<10 cm
NASA HQ Polar Research Program	NAVIGATION	<5 cm<10 m
National Biological Service, North Atlantic Field Station	POSITIONING (SURVEYING)	1 m to 5 m
National Biological Service, North Atlantic Field Station	NAVIGATION (SURVEYING)	
National Biological Service, Colorado Plateau Research Station	NAVIGATION	<3 m.
National Biological Service, Great Lakes Science Center	MARINE NAVIGATION	<15 m
National Biological Service, Great Lakes Science Center	MARINE POSITIONING	<5 m
National Biological Service, Great Lakes Science Center	GIS MAPPING AND SURVEYING (ATTRIBUTE LINKING)	<2 m
National Geodetic Survey	NAVIGATION	<20 m
National Geodetic Survey	POSITIONING (photogrammetry)	<5 m
US Dept. of the Interior, National Park Service	POSITIONING	<5 m
US Dept. of the Interior, National Park Service	MAPPING	<3 m
US Dept. of the Interior, National Park Service	NAVIGATION	<10 m
US Dept. of the Interior, National Park Service	SURVEYS	<5 cm
US Dept. of the Interior, National Park Service	POSITIONING (LOCATION OF ARTIFACTS)	<3 m

INFORMATION FROM 1996 USER SURVEY FOR L5		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
US Dept. of the Interior, National Park Service	POSITIONING	1 m
US Dept. of the Interior, National Park Service	POSITIONING	<3 m accuracy with 1 sec integrity
National Science Foundation, Division of Earth Sciences, Directorate for Geosciences	POSITIONING	<2 m
National Science Foundation, Oceanographic Centers and Facilities	NAVIGATION	<10 m
National Science Foundation, Office of Polar Programs	SURVEYING	< 5 cm
NGS, NOAA	POSITIONING	Undefined
NGS, NOAA	NAVIGATION	Undefined
North Coast Resource Management	MAPPING	< 2m
Shenandoah National Park, Info Mgmt Services	MAPPING	<5 m
Smithsonian Institution, National Air and Space Museum, Center for Earth and Planetary Studies	NAVIGATION	<10 m
Smithsonian Institution, National Air and Space Museum, Center for Earth and Planetary Studies	POSITIONING	<1 m
Spokane County Engineering	SURVEYING AND GIS CONTROL	<3 cm
Rutgers University	NAVIGATION	<8 m
SW Programmer and GPS Consultant-Rutgers	AVL	<3 m
US Bureau of Reclamation	POSITIONING	<2 cm
US Bureau of Reclamation	NAVIGATION	<10 m
US Department of Interior, Bureau of Indian Affairs	POSITIONING	<3 cm

INFORMATION FROM 1996 USER SURVEY FOR L5		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
US Department of Interior, Bureau of Indian Affairs	NAVIGATION	<8 m
US Department of Education		
US Department of Energy; Western Area Power Admin. Montrose, CO	SURVEYING AND MAPPING	<6 m
US Department of Health and Human Services (DHHS), Centers for Disease Control and Prevention, Public Health Practice Program Office	NAVIGATION	<8 m Horizontal and <8 m Vertical
US Department of Health and Human Services (DHHS), Indian Health Service, Office of Information Management Resources, Division of Telecommunications Management	SURVEYING	<1 m
US Department of Interior, Bureau of Indian Affairs	POSITIONING AND NAVIGATION	100 m
US Department of the Interior, Bureau of Indian Affairs, Geographic Data Service Center	POSITIONING AND NAVIGATION	5 m
US Department of Interior, Office of Surface Mining	POSITIONING	< 5 m
US Department of Justice, Law Enforcement Support	TIMING AND POSITIONING	100 m
US Geological Survey	VOLCANO MONITORING	1 cm
US Geological Survey	TECTONIC DEFORMATION	1 to 3 mm horiz/1-3 cm vertical
US Geological Survey, Water Resources Division and Geologic Division	NAVIGATION	8 m
US Geological Survey, Water Resources Division and Geologic Division	POSITIONING	<1 m
US Information Agency	TIMING AND POSITIONING	<8 m
US Nuclear Regulatory Commission	POSITIONING	1 m
US Nuclear Regulatory Commission	TRACKING	<100 m

INFORMATION FROM 1996 USER SURVEY FOR L5		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
US Postal Service, HQ Engineering	MAPPING AND AVL	<25 m
USCG R&D Center	NAVIGATION	<8 m
USCG R&D Center	SURVEYING	<1 m
USCG R&D Center	TIMING	
USEPA	NAVIGATION	<25 m
USEPA	POSITIONING	<5 m
USEPA	AERIAL/MARINE NAVIGATION	<5 m
Washington Dept. of Natural Resources	GEODETIC CONTROL FOR BOUNDARY SURVEYS	<2 cm
Washington Dept. of Natural Resources	PHOTOGRAMMETRIC CONTROL	1.5 m
Washington Dept. of Natural Resources	MAPPING	12 m
Worcester Polytechnic Institute-Dept. of Elect and Comp Eng	POSITIONING	<8 m
Worcester Polytechnic Institute-Dept. of Elect and Comp Eng	NAVIGATION	<10 m
Wrangell-St. Elias National Park and Preserve, Copper Center, Alaska	POSITIONING	<5 m
Wrangell-St. Elias National Park and Preserve, Copper Center, Alaska	NAVIGATION	<15 m

APPENDIX B2: RESULTS OF 1997 REVALIDATION STUDY - FEDERAL AGENCIES' AND OTHER ORGANIZATIONS' APPLICATIONS OF DGPS

INFORMATION FROM 1997 USER STUDY		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
ATF	TRACKING	< 20m
DEA	TRACKING/POSITIONING	30 - 50 m
DOE - Office of Trans. Emergency Management & Analytical Resources	POSITIONING/TRACKING	< 50m
DOI/ Bureau of Indian Affairs	POSITIONING/NAVIGATION	4-8 m
DOI/ Bureau of Land Management	SURVEYING/MAPPING POSITIONING/NAVIGATION	<1-5m
DOI/ Bureau of Reclamation	SURVEYING/MAPPING /NAVIGATION	<1-5m
DOI/U.S. Fish and Wildlife Service	SURVEYING/MAPPING /NAVIGATION	<1-5m
DOI/ Minerals Management Service	POSITIONING	<8m
DOI/ National Park Service	SURVEYING/MAPPING POSITIONING/NAVIGATION	<1-5m
	MAPPING (ARCHEOLOGY)	1m
DOI/ Office of Surface Mining	MAPPING/POSITIONING	1-5m
DOI/ U.S. Geological Survey	SURVEYING/MAPPING POSITIONING/NAVIGATION	<5m
EPA	POSITIONING	1 - 5 m
	NAVIGATION	1m
FBI	POSITIONING/TRACKING	3 - 7 m
FEMA	POSITIONING/SURVEYING	5 - 10 m
FHWA	POSITIONING/NAVIGATION	< 10m
FRA	POSITIONING/NAVIGATION	< 10m
MMS	POSITIONING	< 8m

INFORMATION FROM 1997 USER STUDY		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
NASA - GSFC	POSITIONING	few cms
NASA - JBL	NAVIGATION/RESEARCH	20 cm - 2m
NASA - Marshal Space Flight Center	SCIENTIFIC MEASUREMENTS	< 1m
NGS	MAPPING	< 1m
Patuxent Wildlife Research	POSITIONING	< 8m
Smithsonian Facility/GIS Lab	POSITIONING	< 8m
US Forest Service	NAVIGATION/POSITIONING	< 10m
NPS - North Atlantic Station	NAVIGATION/SURVEYING	< 1m
USPS	POSITIONING/TRACKING	< 20m
USCG	POSITIONING/NAVIGATION	< 10m
Iowa - Agronomist	SURVEYING/MAPPING	2 - 5m
Texas Parks & Wildlife	SURVEYING/MAPPING	3 - 4 m
Iowa - Dept. of Public Safety	POSITIONING/NAVIGATION	< 10m
Dept. of Natural Resources	SURVEYING	< 15m
Washington State	POSITIONING/SURVEYING	< 8m
Washington Dept. of Natural Resources	SURVEYING	1 - 8 m
Northwest Florida Water Management District	SURVEYING/POSITIONING	< 5m
New York - Tompkins County	POSITIONING/TRACKING/NAVIGATION	< 10m
California Dept. of Forestry & Fire Protection	MAPPING/NAVIGATION	< 20 m
Washington - Spokane County Engineering	SURVEYING/POSITIONING	1 - 8 m
California - General Services & Telecommunications	SURVEYING/NAVIGATION	< 10 m
California Highway Patrol	TRACKING/POSITIONING	< 8m

INFORMATION FROM 1997 USER STUDY		
ORGANIZATION	APPLICATION	ACCURACY REQUIREMENT
New Jersey DOT	SURVEYING/POSITIONING	3m
Montana DOT	SURVEYING	< 5m
Nebraska DOT	SURVEYING/NAVIGATION/POSITIONING	< 8m
Nebraska - Land Surveying	SURVEYING	3m
Wisconsin DOT	SURVEYING/POSITIONING	< 5m
Maine - Bureau of Conservation	SURVEYING/POSITIONING	1 - 8 m
Minnesota DOT	SURVEYING/POSITIONING	< 5m
Minnesota Pollution Control Agency	POSITIONING	< 3 m
Minnesota Dept. of Health	POSITIONING	< 5m
Minnesota Dept. of Agriculture	SURVEYING/POSITIONING	2 - 8 m
Kansas Department of Health and Environment	POSITIONING	< 5m
Connecticut Dept. of Environmental Protection	POSITIONING/SURVEYING	1 - 10 m
South Dakota DOT	NAVIGATION/POSITIONING	2 - 10 m
Voyager National Park, MN	SURVEYING/NAVIGATION	1 - 15 m
Department of Health and Human Services - Indian Health Services	POSITIONING/NAVIGATION	< 20 m

APPENDIX C1: DETAILED COST ESTIMATE FOR NEW DGPS SITE

NOTE: It is difficult to develop an accurate estimate without the benefit of a specific site Installation Design Plan (IDP). Substantial cost reductions are achieved by the use of in-house personnel. Substantial cost increases are required due to poor soil, long distances to electrical/telcom service, and unusual environmental concerns and/or mitigation. This rough order estimate assumes all work is contracted.

***Site Design and Planning*:**

- Develop Site Plan		$25,000
- Develop Installation Design Plan (IDP)		$25,000
- Develop Environmental Assessment (EA)		$25,000
- Electro-Magnetic Compatibility (EMAG) Study		$3,000
- Site Operational Verification Testing (SOVT)		$10,000
- As-Built Drawing Set		$5,000
	Sub Total:	$93,000

***MF Broadcast Antenna System*:** (NOTE - two different transmit antenna types are provided, the sub-total is based on the more expensive, higher efficiency antenna.)

VALCOM (74' free standing whip utilized when required range is 70 NM or less.)

- VALCOM antenna and accessories		$9,000
- VALCOM antenna foundation		$10,000
- RF Ground system materials		$6,000
- RF Ground system install		$15,000
- Transmission line and conduit		$1,000
- Antenna Tuning Unit (ATU) foundation		$5,000
- Safety fence		$2,000
- Antenna assembly and erection		$5,000
	Sub Total:	$53,000

Top-Loaded Monopole (TLM) (120' guyed tower utilized when required range is > 70 NM.)

- Tower sections, guy wire, hardware, and insulators		$9,000
- Base and guy anchor foundations		$15,000
- RF Ground system materials		$6,000
- RF Ground system install		$15,000
- Transmission line and conduit		$1,000
- Antenna Tuning Unit (ATU) foundation		$5,000
- Safety fence		$2,000
- Antenna assembly and erection		$27,000
	Sub Total:	$80,000

***Equipment Shelter*:** (NOTE- two different shelter types are provided, the subtotal used in the total is for the preferred concrete; both shelters come with pre-wired electrical distribution, interior lightning, and air-conditioning/heat.)

Concrete Shelter (Advantage is lowest maintenance and bullet proof, but heavy for site delivery.)

- Andrews shelter, concrete (includes shipping)		$25,000
- Shelter foundation		$5,000
- Clearing and grading		$2,000
- Stone path		$3,000
- Ground system materials and installation		$2,000
- Power feeder		$3,000 *
- Telephone feeder		$1,000 *
- X.25 Install		$1,200
	Sub Total:	$42,200

*NOTE - These costs can be much higher depending on the distance from the site to existing power and telephone service lines.

Fiberglass Shelter (Advantage is can be helo lifted to site, but requires higher maintenance.)

- Fiberglass shelter (includes shipping)	$35,000	
- Shelter foundation	$5,000	
- Clearing and grading	$2,000	
- Stone path	$3,000	
- Ground system materials and installation	$2,000	
- Power feeder	$3,000	*
- Telephone feeder	$1,000	*
- X.25 Install	$1,200	
Sub Total:	$52,200	

*NOTE - These costs can be much higher depending on the distance from the site to existing power and telephone service lines.

GenSet Shelter: (If local commercial power has historical availability lower that 99.7% monthly then site emergency power is a requirement; however, new USCG transmitter can be backed-up for 24 hours on battery bank and each of the above equipment huts are sized for electronics and battery bank. Battery back-up should be considered as alternative to GenSet to achieve lower implementation and maintenance costs.

- Turn-key GenSet facility (LP or Natural gas)	$25,000
- Shelter foundation	$5,000
- Power feeder connection	$1,000
- Ground system installed	$1,000
Sub Total:	$32,000

Transmitter and ATU: (The USCG is expected to award a contact from new 1kW MF transmitters in April, 1997 and this estimate is based on the projected per unit cost under that contract. The new transmitter is speced to include site monitoring and control to replace the function of the current Differential Broadcast Site Monitor (DBSM) equipment. DBSM cost is therefore not listed under the DGPS equipment estimate in the following category.)

- MF Transmitter (1000 W) and ATU	$20,000
- Installation labor	$10,000
- Misc installation materials	$2,000
Sub Total:	$32,000

DGPS Equipment: (NOTE - The cost of Differential Broadcast Site Monitor (DBSM) is not included in the following estimate as it is assumed that new MF transmitters will be used that provide the site monitoring and control function; see comments for Transmitter and ATU in the preceding category. For reference to the Appleton prototype, which will have DBSM installed with a non-standard MF transmitter, the cost of DBSM and the required on-site spares is $9500 per suite.

- Reference Stations (2) with GPS antennas	$47,816	(GSA contract price)
- Integrity Monitors (2) with antennas (GPS & MSK)	$38,790	(GSA contract price)
- Standard equipment rack	$3,000	
- Packet Assembler/Disassembler (PAD)	$3,900	
- Uninteruptable Power Supply (UPS)	$1,006	
- Lightning Protection	$174	
- Misc materials, cables, and installation labor/travel	$25,200	(Appleton actual labor install)
Sub Total:	$119,886	

Site GPS Antenna Masts: (Cost is for two masts, each 30' high)

- 3 Mast sections (10' each)	$1,590	
- 2 short base sections (embedded in concrete foundation)	$191	
- Hardware	$64	
- Anti-climb Guards (6 sheets)	$750	
- 2 Mast Crossbars (GPS antenna mounts)	$48	
- Two poured concrete foundations	$12,000	(Appleton actual labor install)
- Conduit, misc materials and installation labor	$8,000	(Appleton actual labor install)
Sub Total:	$22,643	

Training: (5 day course available at the USCG NATON School at Yorktown, VA)

- Perdiem and travel per tech	$2,000
Sub Total:	$2,000

Grand total for new site implementation costs: $423,729

NOTE - The grand total should be considered a conservative average figure. Unusual site conditions can run costs up quickly. One USCG west coast site cost an additional $90K for archeologist on site during foundation excavations due to possible Indian burial ground near property.

APPENDIX C2: DETAILED COST ESTIMATE FOR GWEN SITE USE

NOTE: It is difficult to develop an accurate estimate without the benefit of experience. After the Installation Design Plan (IDP) developed for Appleton GWEN site is implemented, this estimate should be updated with actual Appleton costs. One of the largest advantages of retrofitting a GWEN site is negating the environmental and MF antenna work.

Site Design and Planning:		
- Develop Site Plan		$2,000
- Develop Installation Design Plan (IDP)		$1,000
- Develop Environmental Assessment (EA)		$0
- Electro-Magnetic Compatibility (EMAG) Study		$0
- Site Operational Verification Testing (SOVT)		$10,000
- As-Built Drawing Set		$5,000
	Sub Total:	$18,000
MF Broadcast Antenna System:		
Top-Loaded Monopole (TLM) (301' guyed GWEN tower and transmission line reutilized)		
	Sub Total:	$0
Equipment Shelter: (NOTE- long term maintenance cost to maintain the WX integrity of the GWEN metal shelter has not been researched. This recurring cost needs to be assessed when cost comparing reuse of the GWEN shelter vice replacing it with a concrete bullet-proof shelter.)		
Concrete Shelter (Advantage is lowest maintenance and bullet proof, but heavy for site delivery.)		
- Andrews shelter, concrete (includes shipping)		$25,000
- Shelter foundation		$5,000
- Removal of GWEN hut		$4,000
- Clearing, grading and stone path		$0
- Ground system materials and installation		$0
- Power feeder		$0
- Telephone feeder		$0
- X.25 Install		$1,200
	Sub Total:	$35,200
GWEN RN Shelter (Advantage is lower implementation cost, but may require higher maintenance.)		
- Modify LF WX entry point		$150
- Modify voice telephone wiring		$150
- Remove USAF electronics and cabling		$500
- X.25 Install		$1,200
	Sub Total:	$2,000
GenSet Shelter: (If local commercial power has historical availability lower that 99.7% monthly then site emergency power is a requirement; however, new USCG transmitter can be backed-up for 24 hours on battery bank. However, there is not enough room in the USAF RN shelter to house the battery bank with the electronics. Battery back-up should be considered as alternative to achieve lower recurring facility maintenance costs.		
- reuse of USAF Back-up Power Generator (BUPG)		$0
	Sub Total:	$0
Transmitter and ATU: (The USCG is expected to award a contact from new 1kW MF transmitters in April, 1997 and this estimate is based on the projected per unit cost under that contract. The new transmitter is speced to include site monitoring and control to replace the function of the current Differential Broadcast Site Monitor (DBSM) equipment. DBSM cost is therefore not listed under the DGPS equipment estimate in the following category.)		
- MF Transmitter (1000 W) and ATU		$20,000
- Installation labor		$10,000
- Misc installation materials		$2,000
	Sub Total:	$32,000

DGPS Equipment: (NOTE - The cost of Differential Broadcast Site Monitor (DBSM) is not included in the following estimate as it is assumed that new MF transmitters will be used that provide the site monitoring and control function; see comments for Transmitter and ATU in the preceding category. For reference to the Appleton prototype, which will have DBSM installed with a non-standard MF transmitter, the cost of DBSM and the required on-site spares is $9500 per suite.

- Reference Stations (2) with GPS antennas		$47,816
- Integrity Monitors (2) with antennas (GPS & MSK)		$38,790
- Standard equipment rack		$3,000
- Packet Assembler/Disassembler (PAD)		$3,900
- Uninteruptable Power Supply (UPS)		$1,006
- Lightning Protection		$174
- Misc materials, cables, and installation labor/travel		$25,200
	Sub Total:	$119,886

Site GPS Antenna Masts: (Cost is for two masts, each 30' high)

- 3 Mast sections (10' each)		$1,590
- 2 short base sections (embedded in concrete foundation)		$191
- Hardware		$64
- Anti-climb Guards (6 sheets)		$750
- 2 Mast Crossbars (GPS antenna mounts)		$48
- Two poured concrete foundations		$12,000
- Conduit, misc materials and installation labor		$8,000
	Sub Total:	$22,643

Training: (5 day course available at the USCG NATON School at Yorktown, VA)

- Perdiem and travel per tech		$2,000
	Sub Total:	$2,000

Grand total for reuse of GWEN site:	**$196,529**

APPENDIX C3: DETAILED COST ESTIMATE FOR RELOCATED GWEN EQUIPMENT

NOTE: It is difficult to develop an accurate estimate without the benefit of experience in actually relocating a GWEN tower and shelters. Disassemble and relocation estimates provided are based on USAF experience in June 1996 to remove a tower and both shelters from Elmira NY. The shelters were reinstalled at Elmira NY and the tower was sent to government surplus disposal (DRMO) at Ft. Drum NY. This rough order estimate assumes all work is contracted. Substantial cost increases are required due to poor soil at the new site or long distances to electrical/telecom service or unusual environmental concerns and/or mitigation. It has been the recent experience of the USCG that guyed towers now often require installation of bird diverter devices to reduce the risk to migratory birds from collisions with tower guy wires.

Site Design and Planning:	
- Develop Site Plan	$22,000
- Develop Installation Design Plan (IDP)	$25,000
- Develop Environmental Assessment (EA)	$25,000
- Electro-Magnetic Compatibility (EMAG) Study	$3,000
- Site Operational Verification Testing (SOVT)	$10,000
- As-Built Drawing Set	$5,000
Sub Total:	$90,000

MF Broadcast Antenna System: (NOTE - estimates for a 120' TLM guyed tower antenna are provided for comparison purpose with relocating a GWEN. The USAF reports having three or four GWEN towers in storage as system spares. These should be requested to save disassemble and crating costs.)

GWEN Top-Loaded Monopole (TLM) (300' guyed tower)	
- Lower and disassemble tower	$15,000
- Inspect and crate tower for shipment	$3,000
- Ship tower to new site	$3,000
- Procure non-reusable tower hardware	$1,000
- Base and guy anchor foundations	$20,000
- RF Ground system materials	$7,000
- RF Ground system install	$16,500
- Transmission line and conduit	$1,000
- Antenna Tuning Unit (ATU) foundation	$5,000
- Safety fence	$2,000
- Antenna assembly and erection	$30,000
Sub Total:	$103,500
Top-Loaded Monopole (TLM) (120' guyed tower utilized when required range is > 70 NM.)	
- Tower sections, guy wire, hardware, and insulators	$9,000
- Base and guy anchor foundations	$15,000
- RF Ground system materials	$6,000
- RF Ground system install	$15,000
- Transmission line and conduit	$1,000
- Antenna Tuning Unit (ATU) foundation	$5,000
- Safety fence	$2,000
- Antenna assembly and erection	$27,000
Sub Total:	$80,000

Equipment Shelter: (NOTE- long term maintenance cost to maintain the WX integrity of the GWEN metal shelter has not been researched. This recurring cost needs to be assessed when cost comparing reuse of the GWEN shelter vice replacing it with a concrete bullet-proof shelter.)

Concrete Shelter (Advantage is lowest maintenance and bullet proof, but heavy for site delivery**.)**	
- Andrews shelter, concrete (includes shipping)	$25,000
- Shelter foundation	$5,000
- Clearing, grading and stone path	$5,000

- Ground system materials and installation	$2,000
- Power feeder	$3,000
- Telephone feeder	$1,000
- X.25 Install	$1,200
Sub Total:	$42,200

*NOTE - These costs can be much higher depending on the distance from the site to existing power and telephone service lines.

GWEN RN Shelter (Advantage is lower implementation cost, but may require higher maintenance.)

- Modify LF WX entry point	$150
- Modify voice telephone wiring	$150
- Remove USAF electronics and cabling	$500
- Prep Shelter for loading/shipment	$2,500
- Load, ship and off-load shelter	$3,500
- Shelter foundation	$5,000
- Clearing, grading and stone path	$5,000
- Ground system materials and installation	$2,000
- Power feeder	$3,000
- Telephone feeder	$1,000
- X.25 Install	$1,200
Sub Total:	$23,700

*NOTE - These costs can be much higher depending on the distance from the site to existing power and telephone service lines.

GenSet (BUPG) Shelter: (If local commercial power has historical availability lower that 99.7% monthly then site emergency power is a requirement; however, new USCG transmitter can be backed-up for 24 hours on battery bank. However, there is not enough room in the USAF RN shelter to house the battery bank with the electronics. Battery back-up should be considered as alternative to GenSet to achieve lower recurring facility maintenance costs.

- Prep BUPG Shelter for loading/shipment	$2,500
- Load, ship and off-load shelter	$3,500
- Shelter foundation	$5,000
- Power feeder connection	$1,000
- Ground system installed	$1,000
Sub Total:	$10,500

Transmitter and ATU: (The USCG is expected to award a contact from new 1kW MF transmitters in April, 1997 and this estimate is based on the projected per unit cost under that contract. The new transmitter is speced to include site monitoring and control to replace the function of the current Differential Broadcast Site Monitor (DBSM) equipment. DBSM cost is therefore not listed under the DGPS equipment estimate in the following category.)

- MF Transmitter (1000 W) and ATU	$20,000
- Installation labor	$10,000
- Misc installation materials	$2,000
Sub Total:	$32,000

DGPS Equipment: (NOTE - The cost of Differential Broadcast Site Monitor (DBSM) is not included in the following estimate as it is assumed that new MF transmitters will be used that provide the site monitoring and control function; see comments for Transmitter and ATU in the preceding category. For reference to the Appleton prototype, which will have DBSM installed with a non-standard MF transmitter, the cost of DBSM and the required on-site spares is $9500 per suite.

- Reference Stations (2) with GPS antennas	$47,816
- Integrity Monitors (2) with antennas (GPS & MSK)	$38,790
- Standard equipment rack	$3,000
- Packet Assembler/Disassembler (PAD)	$3,900
- Uninterruptable Power Supply (UPS)	$1,006
- Lightning Protection	$174
- Misc materials, cables, and installation labor/travel	$25,200
Sub Total:	$119,886

Site GPS Antenna Masts: (Cost is for two masts, each 30' high)

- 3 Mast sections (10' each)	$1,590
- 2 short base sections (embedded in concrete foundation)	$191
- Hardware	$64
- Anti-climb Guards (6 sheets)	$750
- 2 Mast Crossbars (GPS antenna mounts)	$48
- Two poured concrete foundations	$12,000
- Conduit, misc materials and installation labor	$8,000
Sub Total:	$22,643

Training: (5 day course available at the USCG NATON School at Yorktown, VA)

- Perdiem and travel per tech	$2,000
Sub Total:	$2,000
Grand total for relocation of GWEN site:	**$404,229**

APPENDIX C4: ANNUAL OPERATING AND MAINTENANCE COST PER SITE

Estimate of Annual Recurring Operating Expenses for One Site:

Property Lease:	$5,000 *	
*NOTE - this estimate is based on the average of thirty eight (38) GWEN leased sites.		
Utilities:		
Electrical:	$9,000	
Telephone:	$1,200	
X.25 Circuit:	$2,000	
Generator Fuel:	$200	
Subtotal:	$12,400	
Operating Cost Estimate	**$17,400**	
Maintenance:		
Electronics:	$12,000	
Facility:	$15,000	(grass cutting, tower inspections/light repair, GenSet service)
Maintenance cost:	**$27,000**	
Grand Total:	**$44,400**	

APPENDIX C5: COST ESTIMATES FOR CONTROL STATION EXPANSION AND ANNUAL OPERATING AND MAINTENANCE COST ESTIMATE

Note: The following expansion and recurring costs are those expected for the day-to-day monitoring and control of approximately 50 non-maritime DGPS Broadcast sites. These estimates include expansion (one-time) and recurring (annual) costs for Control Station operations and site equipment support at the Depot and Intermediate levels. The basis for this estimate is that one new set of Control Station equipment with associated X.25 communication circuits will be installed at the existing CG East Control Station in Alexandria VA with additional personnel assigned to support the day-to-day operations of these non-maritime sites to meet requirements of the non-maritime users.

expansion of Control Station for other modal users:

Item	Item Price	# Items	Total Item Cost
TAC3 computer -	$18,000.00	2	$36,000.00
128MB RAM expansion -	$12,800.00	2	$25,600.00
Hard Drive -	$1,000.00	6	$6,000.00
CD ROM Drive -	$250.00	2	$500.00
PAD Card -	$1,870.00	4	$7,480.00
Print Card -	$690.00	2	$1,380.00
Laser Printer -	$2,440.00	2	$4,880.00
DAT Drive -	$1,400.00	2	$2,800.00
19" Monitor -	$1,200.00	6	$7,200.00
Graphics Card -	$2,310.00	2	$4,620.00
X-window -	$1,300.00	2	$2,600.00
UNIX HP Op Sys -	$900.00	2	$1,800.00
MATLAB -	$500.00	2	$1,000.00
ORACLE V7.0 -	$12,000.00	2	$24,000.00
Console with two chairs -	$15,000.00	1	$15,000.00
X.25 drop installation (56kbs) -	$1,700.00	2	$3,400.00
		Subtotal:	$144,260.00

Annual Costs for operation of Control Station for other modal users:

	Annual Salary	Number	Annual Cost
Watchstanders (3@E6;3@E5) -	$52,500.00	6	$315,000.00
Inland Duty Officer (CWO)	$74,020.50	2	$148,041.00
Control Station Supervisor (E7)	$53,771.00	1	$53,771.00
	Staff Salary Subtotal:		$516,812.00
X.25 Annual Cost -			$51,000.00
Misc Administrative (Supplies, Training & Travel) Costs -			$15,000.00
	Operating Subtotal:		$66,000.00
		Subtotal:	$582,812.00

Implementation of Depot Support for 50 sites:

	Unit Price	# Units	15% Spare Cost
15% spare RS units -	$16,000.00	15	$240,000.00
15% spare IM units -	$16,000.00	15	$240,000.00
15% spare PADs -	$3,900.00	8	$31,200.00
15% spare UPS -	$1,006.00	8	$8,048.00
15% spare RBn Xmtr with ATU -	$20,000.00	8	$160,000.00
Spare antennas -	$15,000.00	1	$15,000.00
			$694,248.00

Recurring Costs for Depot Support for 50 sites:

NOTE: The following estimate includes the recurring costs associated with management of the depot level electronics support (repair, quality assurance, shipping and handling) for 50 broadcast sites. Based on USCG DGPS Depot experience one technician is required to provide for QA, inventory, and handling labor. Included is depot level support for all equipment listing in Depot expansion cost estimate category above.

	Annual Salary	Number	Annual Cost
Senior Technician (E-6)	$52,500.00	1	$52,500.00
	Staff Salary Subtotal:		$52,500.00
Annual shipping costs -			$7,500.00
Annual cost for equipment repair contracts -			$33,000.00
		Subtotal:	$40,500.00

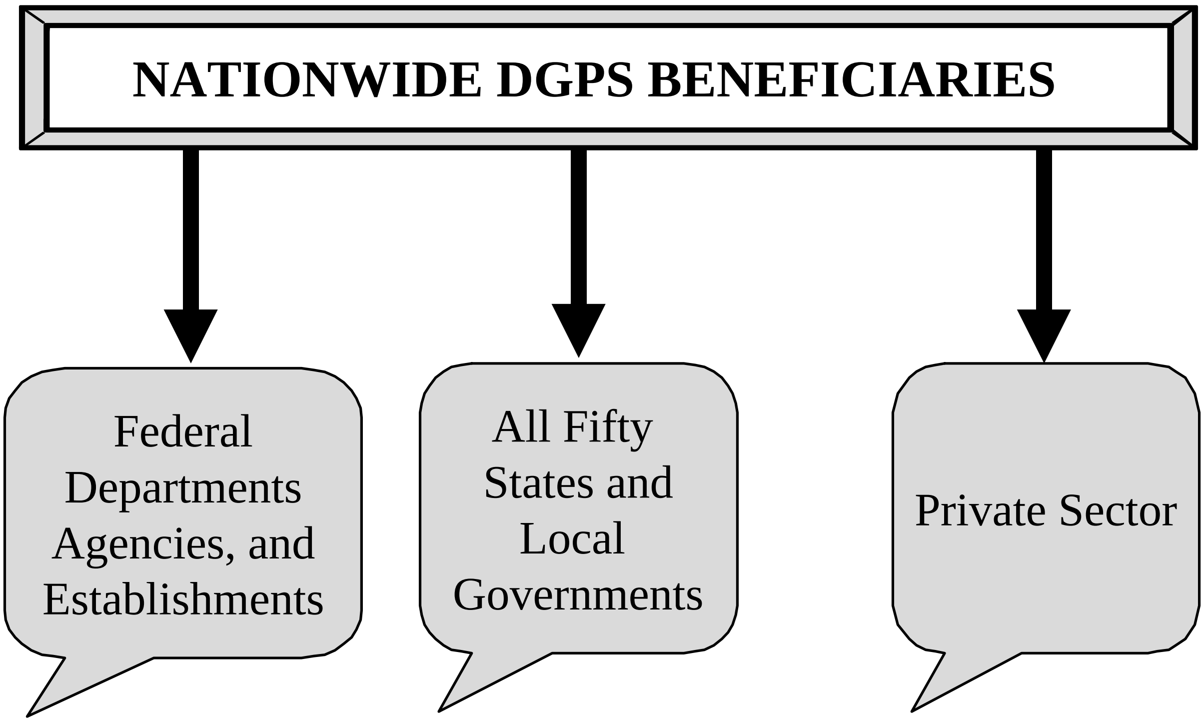
Recurring Costs for MLC Intermediate Level Support for 50 sites:

NOTE: The following estimate includes the recurring costs associated with management of the electronics and facility maintenance contract(s) for 50 broadcast sites. Based on USCG DGPS maintenance contracting experience one contract specialist and one senior technician is required for each 25 sites contracted. The contract specialist handles contract management and negotiations and the senior technician handles contract quality assurance/verification 'which includes one annual visit to each site contracted.

	Annual Salary	Number	Annual Cost
Contract Specialist (GS-12)	$74,020.50	2	$148,041.00
Senior Technician (E-7)	$53,771.00	2	$107,542.00
	Staff Salary Subtotal:		$255,583.00
Annual Travel Costs for one contract QA visits per site -			$50,000.00
Annual Travel Costs for two technical assist visits -			$10,000.00
Contingency Funds for catastrophic failure response -			$10,000.00
		Subtotal:	$325,583.00

Total Control Station Expansion and Support Costs:	**$838,508.00**
Total Control Station and Support Annual Costs:	**$948,895.00**

APPENDIX D: BENEFICIARIES OF A NATIONWIDE DGPS



Federal Departments Agencies, and Establishments

» **DOA**
» **DOJ**
» **DOI**
» **DOT**
» **DOD**
» **DOTres.**
» **EPA**
» **NTSB**
» **USPS**
» **FEMA**
» **Others**

All Fifty States and Local Governments

» **Law Enforcement**
» **DOT's**
» **Water Management Departments**
» **Land Management Agencies**
» **Health Departments**
» **Pollution Control Agencies**
» **Emergency Response Groups and Disaster Relief Agencies**
« **Others**

Private Sector

» **DGPS Manufacturers**
» **DGPS Equipment Resellers**
» **Research**
» **Railroad Industry**
» **Agricultural Industry**
» **Others**

APPENDIX E: GEOSTATIONARY SATELLITE COVERAGE

Geostationary Satellite Coverage

By: James A. Arnold, Federal Highway Administration

1.0 Introduction

This paper explores the issues associated with surface coverage of a geostationary satellite broadcast of Differential GPS corrections. A geostationary satellite is roughly defined as orbiting at a radius of 42,242 km, lying in the plane of the equator and appearing to an observer on the ground to be constantly above the same point on the earth. This signal reception from a geostationary satellite represents a serious concern for users on the surface where there is a potential for multipath, shadowing, and blockage of the satellite signal due to natural and manmade obstructions.

2.0 Satellite Coverage

2.1 Satellite Elevation Angle The first consideration that must be addressed is the elevation angle of the satellite above the horizon. Figure E-1 illustrates the problem.

Figure E-1. Parameters of geostationary satellite coverage

For a geostationary satellite to be visible by a station on the surface of the earth its elevation angle, El, must be above some minimum value, which for this task is assumed to be 0 degrees. A positive or zero angle requires:

Equation 1. Angle of elevation

$$r_s \geq \frac{r_e}{\cos(\gamma)}$$

This means that the maximum central angle separation between the earth station and the subsatellite point is limited by:

Equation 2. Elevation angle calculation

$$\gamma \leq \cos^{-1}\left(\frac{r_e}{r_s}\right)$$

For a nominal geostationary satellite orbit, this reduces to $\gamma = 81.3^\circ$ for visibility. To avoid propagation problems, such as multipath, associated with extremely low elevation angles a smaller separation between the earth station and the subsatellite point is desirable, such as 10°, is used.[53]

Table E-1 indicates several elevation angles based on the continental US for a satellite with its subsatellite point directly south of the city listed. It should be noted that it is not always possible to ensure that the satellite will be directly south of the intended user.

Table E-1. Elevation Angle for Several Cities of a Geostationary Satellite Located Directly South of the Indicated City

City	Latitude	Satellite Angle	Elevation
Miami, FL	25.7°	59.8°	
New Orleans. LA	29.9°	55.1°	
Washington DC	38.9°	44.9°	
Philadelphia. PA	39.9°	43.8°	
St. Paul. MN	44.9°	38.2°	
Winnipeg, Manitoba	50°	32.7°	
Alberta, BC	55°	27.2°	
Anchorage, AK	61.2°	20.7°	

[53] Timothy Pratt and Charles W. Bostian, Satellite Communications, John Wiley & Sons, New York, 1986.

2.2. East-West Considerations

Since it is not always possible to locate a geostationary satellite directly south of a user, the elevation angle is unlikely to provide optimal signal coverage. If the satellite is east or west of the users position, the elevation angles will be lower. Figure E-2 compares satellite elevation angle, with respect to Washington, DC, with satellite position. Note that for a geostationary satellite to be visible in Washington, DC it must be no farther west then 144° west longitude or no farther east than 10° west longitude, using the 10 degree mask angle from above[54].

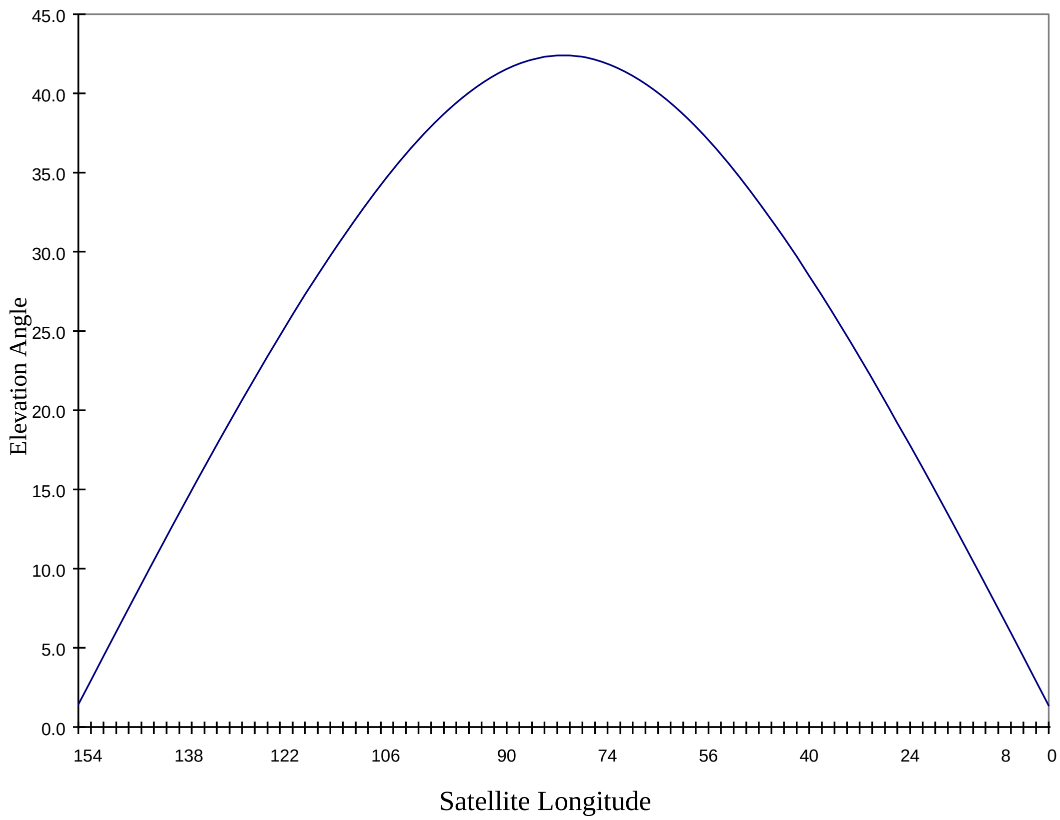


Figure E-2. Geostationary Satellite Elevation Angle, for Washington, DC, versus Subsatellite Longitude

3.0 Surface Obstructions

The previous two sections have laid the ground work for geostationary satellite visibility for users on the surface of the earth, assuming there are no obstructions. Unfortunately there are obstructions on the surface that range in size from mountains to man made obstructions such as buildings. Additionally, signal fading due to tree canopy compounds the problem of surface coverage further.

3.1. Buildings

[54] Note that satellites in geostationary orbits can be no closer than every 2°. This has been agreed to by international treaty.

3.1.1. Single Building.

3.1.1.1. Obscuration by Building Height - Residential. The elevation angle in Washington, DC is approximately 45° for a satellite that is due south. As the satellite is positioned away from due south, the elevation angle worsens until the satellite is obscured by the curvature of the earth. For a satellite due south of Washington DC, the shadow length of a geostationary satellite will be slightly taller than the building creating the shadow. For a typical colonial style house in a Washington, DC suburb, this shadow would be a minimum of 7.6-9.1 meters (25-30 feet) long. In many residential neighborhoods this shadow will stretch well into the street, obscuring much of the roadway from the satellites. Moving farther north, any obscuration due to structures will be greatly increased. As an example, the same Colonial style house placed in St. Paul, MN, would produce a shadow 9.4-11.6 meters (31-38 feet) long. As with the previous example, when the satellites move away from a due south position, the shadow length will increase, as the elevation angle decreases..

3.1.1.2. Obscuration by building height - Commercial. If a geostationary satellite were located due south of a typical 10 story office building found in the Washington, DC area, it would cast a shadow 40 meters (131 feet) long and as wide as the building. If the building were 30.5 meters (100 feet) wide, the shadow would cover approximately 1/3 acre. Figure E-3 illustrates the size of the shadow generated by a 36.5 meter (120 foot) tall by 30.5 meter (100 foot) wide building in Washington DC, depending on the longitude of the geostationary satellite. In St. Paul, MN, this would increase to 0.4 acres. A figure similar to Figure E-3 could be produced to show the shadow in St. Paul, MN. It would have a larger minimum shadow size and be flatter. In essence, the farther north users are located, the more impact shadowing will have.

3.1.2. Multiple Buildings. An argument could be made that the shadow caused by a single building is not significant. For many applications this would be true, except that buildings seldom occur one at a time. Residential construction is producing buildings typically on quarter acre lots or smaller. Commercial buildings are generally grouped together into office parks that comply with strict zoning laws established by local municipalities. For commercial buildings in groups, there would be almost complete shadowing from the south side of the southern most building to 40 meters (131 feet) north of the northern most building, assuming a 10 story building or approximately its height for other buildings and the building location is Washington, DC. With multiple geostationary satellites there will be a small amount of coverage into the eastern and western sides of this group, but not significant due to the elevation angle of the satellite and the density of the structures. If the assumption is made that cities with populations greater than 100,000 have urban centers containing multistory buildings, then there are at least 210 cities in the US where coverage from geo-stationary satellites will not be visible on the surface.[55] Note that this is a conservative estimate and does not include the suburbs of cities such as the Washington, DC suburbs of Silver Spring, Bethesda, and Rockville, MD.

[55] Population Distribution and Population Estimates, US Bureau of the Census, and Department of Commerce Press release CB95-179.

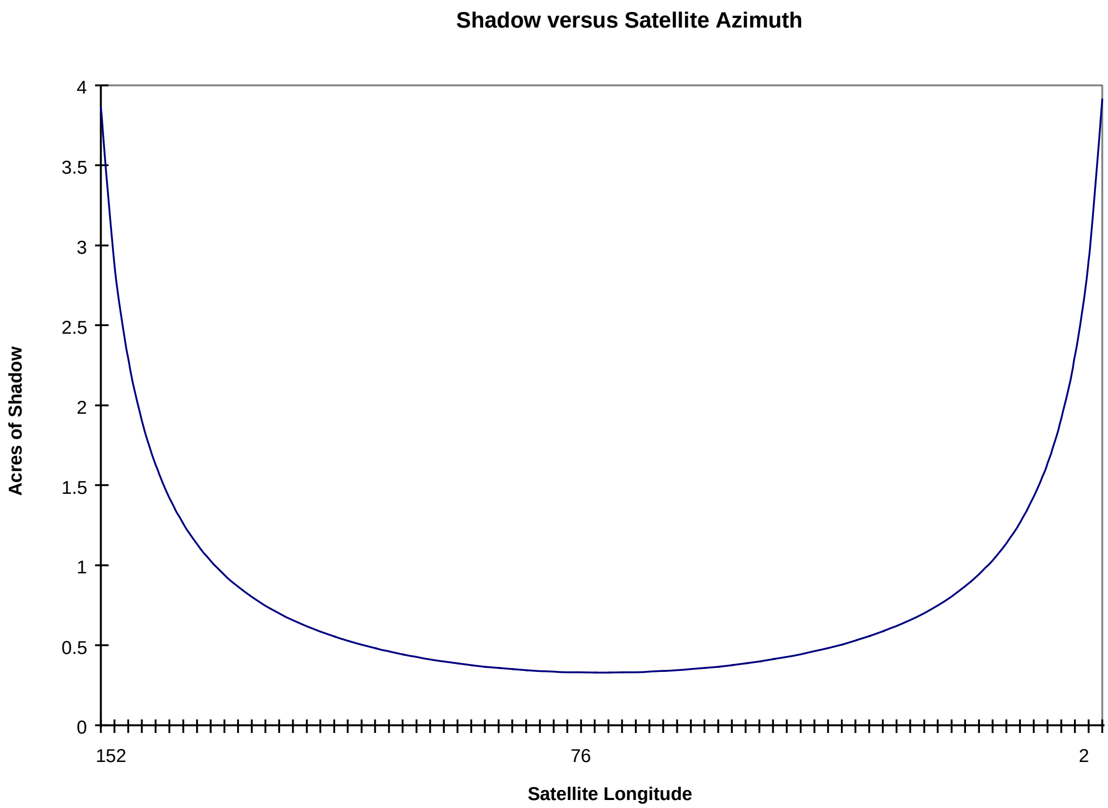


Figure E-3. Shadow Area versus Satellite Longitude for Washington DC.

3.2. Terrain

Obstruction due to terrain will be dominate in mountainous and even hilly terrain where slopes will preclude line of sight reception of the geostationary satellite signal.

3.2.1. Mountains. Obstructions due to terrain will also cause serious blockages. Figure E-4[56] illustrates the terrain in Washington. Figure E-5 is a south to north terrain versus latitude plot. From this it becomes clear that terrain blockage is significant. Note that the data shown here is 30 second terrain data and, in the words of those who compiled the data, the "Digital Terrain Models typically represent an estimate of height for a particular area, not actual or ground truth measurements." The estimating process tends to eliminate or mask data extremes. Instead of selecting the highest or lowest point, an average is developed, masking the actual roughness of the terrain. The higher the resolution, the less significant this factor will be, although it will never be eliminated until very high resolutions are available. The graph of elevation versus latitude covers approximately three degrees or 338 km (210 miles).

[56] Data was obtained from NOAA and consists of 30 second terrain data.

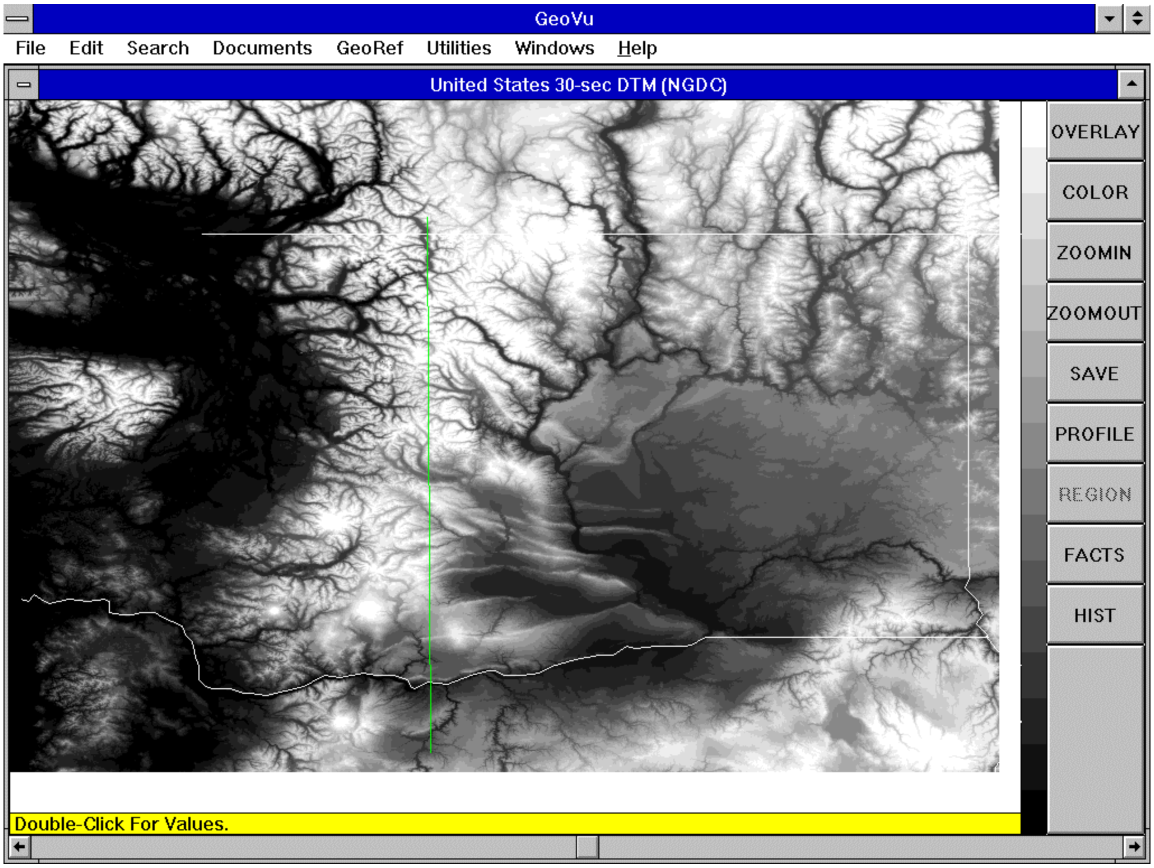


Figure E-4. Terrain map of Washington

For the purposes of this paper it is important to note that mountains are not simply peaks, but tend to run for many miles, forming long and often complicated ridges that join with other mountains. The Rocky Mountains are generally very steep and high. Pikes Peak is 4300 meters (14,110 feet) above sea level. More typical heights are 2400-3600 meters (8,000-12,000 feet)[57], with heights of 900-1500 meters (3000-5000 feet) typical for peak to valley differences. For a mountain 900 meters (3000 feet) above the valley to its north and at a latitude equivalent to Washington DC, it would cast a shadow over 0.8 km (0.5 mile) in length, along its entire length of many miles. If the satellite or group of satellites is positioned west or east of due south, the shadow will lengthen further. In Washington, along the Columbia River Gorge, the difference in height of the mountains surrounding the Gorge and the Gorge itself is 600 meters (2000 feet), the shadow length would be 820 meters (2700 feet) long, obscuring the south slope of the Gorge, the Gorge itself, and a significant portion of the north slope of the Gorge.

[57] World Almanac and Book Of Facts, 1992

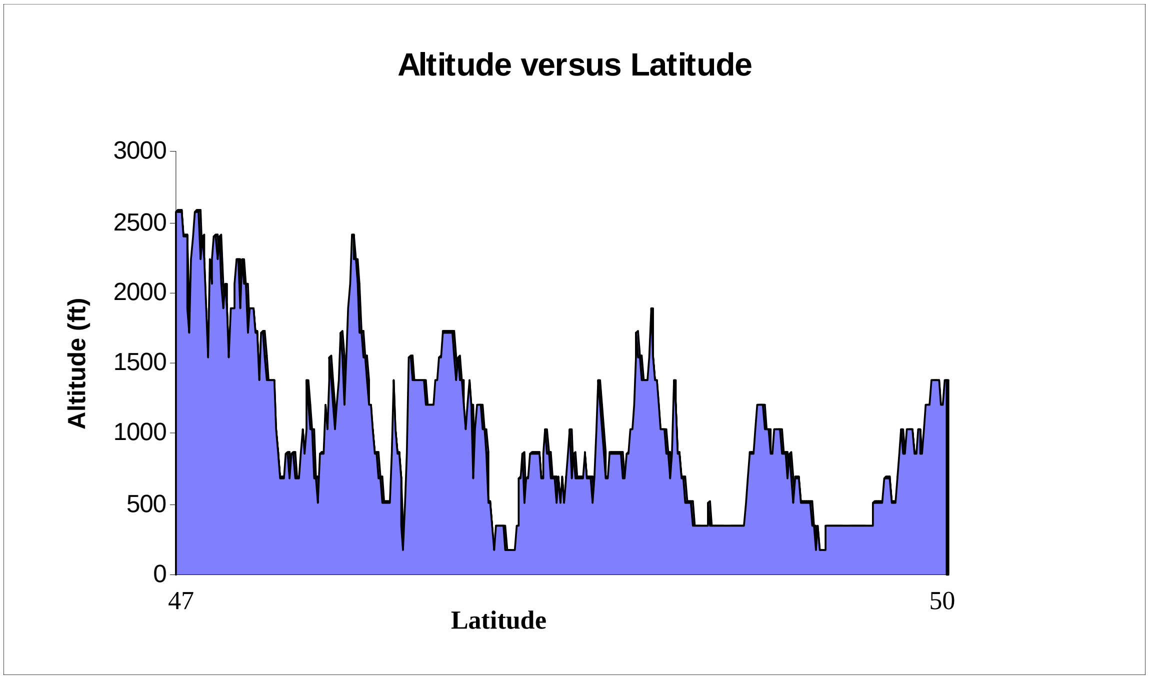


Figure E-5. Elevation versus latitude for Washington

3.3. Diffraction

At some frequencies diffraction of RF radiation may provide some additional coverage. The higher the frequency, the less effect diffraction will have on coverage. For geo-stationary satellites, these frequencies tend to be above 1 GHz, and the contribution of coverage from diffraction is extremely small. Figure E-6 illustrates a simplified version of the diffraction loss expected when the RF energy we are expecting to see encounters a building roof. In order to simplify the calculations, the building is assumed to be a plane of infinite size located at 38° north latitude and the satellite is located directly south, above the equator. This is a good approximation since the satellite we are considering is 42,240 km above the earth's surface and the building is much larger than the wavelength under consideration. Table E-2, calculated for 1575.42 GHz, shows that if the receiver is 100 meters past the edge of the roof and 1 meter into the buildings shadow, there is a greater than 9 dB loss in signal strength. The angle this forms with the direct RF signal is approximately 0.5°. Based on this, the nominal contribution to coverage by diffraction can be eliminated.

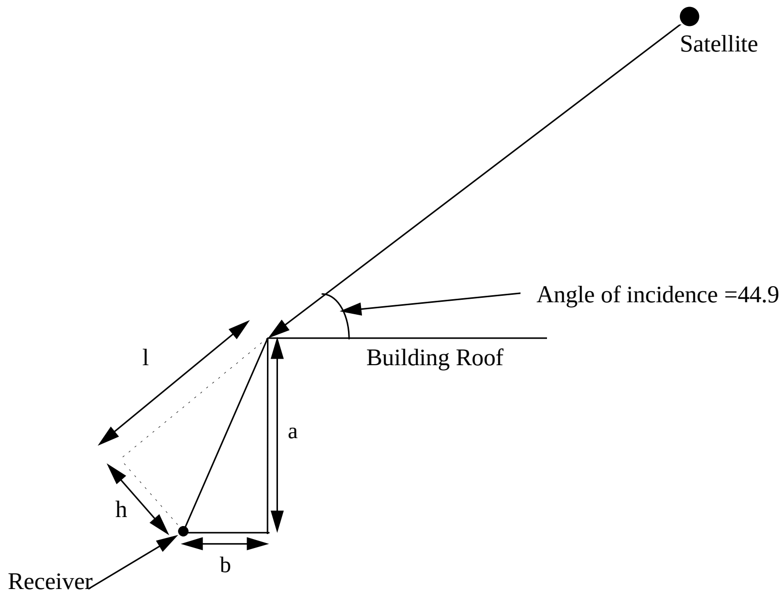


Figure E-6. Diffraction Loss

Table E-2. Diffraction loss as a function of distance into plane shadow.

l (meters)	h (meters)	a (meters)	b (meters)	Loss (dB)
1	1	1.41	0.002	21.42 dB
1	5	4.24	-2.82[58]	NA
1	10	7.79	-6.35	NA
1	20	14.9	-13.4	NA
10	1	7.76	6.37	14.19
10	5	10.6	3.55	26.22
10	10	14.1	.020	31.16
10	20	21.2	-7.03	NA
100	1	71.3	70.1	9.17
100	5	74.1	67.3	17.34
100	10	77.7	63.7	22.81
100	20	84.7	56.7	28.62

[58] Negative numbers indicate the point is within the building structure and power loss would be infinite.

l (meters)	h (meters)	a (meters)	b (meters)	Loss (dB)
1000	1	706.	707.	7.28
1000	5	709.	704.	10.67
1000	10	712.	701.	14.21
1000	20	720.	694.	20.01

3.4. Signal Fading Due to Tree Canopy

The International Telecommunications Union (ITU) has done extensive studies to determine the propagation effects in the land mobile satellite service (LMSS)[59] and how these effects differ from the fixed satellite service (FSS)[60]. The ITU cites the greater importance of terrain effects and the inability to "discriminate against multipath, shadowing, and blockage through the use of highly directive antennas placed at unobstructed sites" by the LMSS as reasons for these additional studies.[61] A segment of this work deals with the issue of tree canopy and the development of an "empirical roadside shadowing model." This model is presented here to provide a point of reference. Many of the applications under consideration are not on roadways and may encounter substantially heavier tree canopy than roadway users would. A specific example of this is the National Biological Services locating and navigating to bird nesting sites in the pacific northwest. The tree canopy has been described as so thick that it is impossible to see more than 5 meters in any direction.

Figure E-7 illustrates fading at 1.57542 GHz due to roadside shadowing versus elevation angle to the satellite. The predicted fade distributions apply for highways and rural roads where the overall aspect of the propagation path is, for the most part, orthogonal to the lines of roadside trees and utility poles and it is assumed that the dominant cause of satellite signal fading is tree canopy shadowing. The percentages, denoted as p, represent the percentage of the distance traveled over which the fade is exceeded. For example, with an elevation angle of 45°, a 3 dB fade is exceeded 20% of the distance traveled, a 9 dB fade is exceeded over 5% of the distance traveled, and a 12 dB fade is exceeded 2% of the distance traveled. These values will be worse as users go further north and better as they go further south.

[59] The Land Mobile Satellite Service uses mobile earth station terminals.

[60] The Fixed Satellite Service uses fixed earth station terminals

[61] Propagation Data Required for the Design of Earth-Space Land Mobile Telecommunication Systems, Annex 1, ITU-R-P681-2.

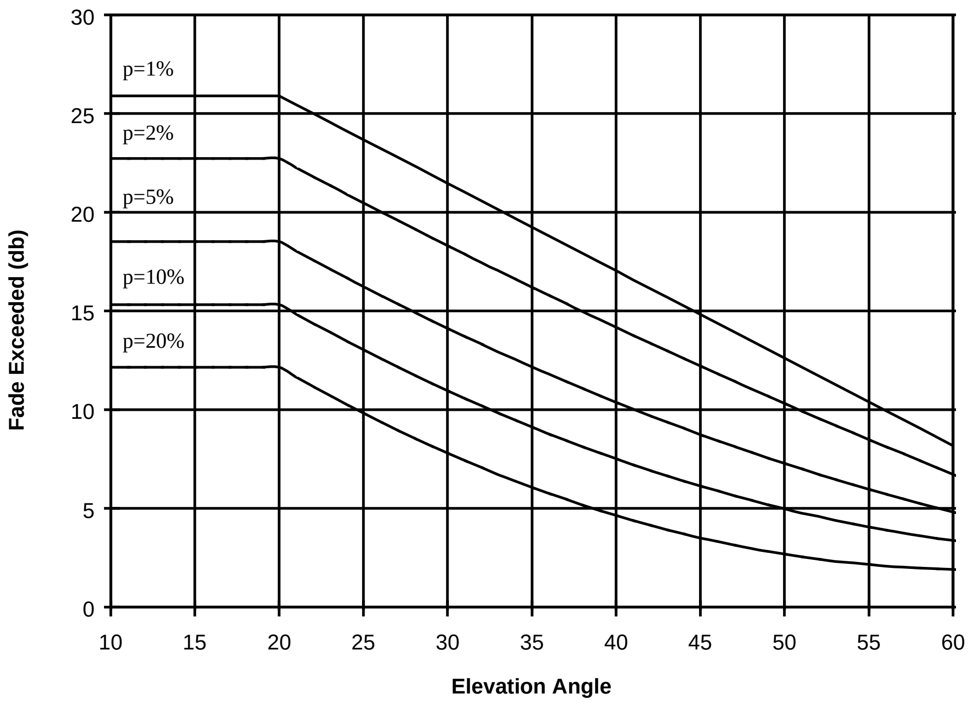


Figure E-7. Fading at 1.57542 GHz versus Path Elevation Angle due to Roadside Shadowing

3.5. Geostationary Coverage. From the above discussions there will be many large holes and many more smaller holes in coverage from geostationary satellites in the country. Areas impacted will include large tracts in mountainous and hilly terrain, forested land such as that found in the eastern and western US, and many urban and suburban areas.

3.6. GPS Coverage. On the other extreme is the coverage from GPS satellites. The 24 satellites in the constellation are in a 55° inclined orbit, 19,000 km (12,000 miles) above the earth. To use GPS for navigation, at least three satellites must be available for a 2 dimensional fix (latitude and longitude). If altitude is needed, then four satellites must be used. There will be a limited number areas and times when there are an insufficient number of satellites visible to navigate. An important point to remember is that these areas and times are not fixed. There will be times, in many cases, where sufficient satellites will be available. As such, GPS is considered to be ubiquitous over much of the world. The GPS constellation was designed to be used by military personnel on the surface of the Earth. The satellite orbits were chosen to provide maximum coverage for surface users. Short of providing differential GPS signals from the GPS satellites themselves, it is unlikely that a geostationary satellite based solution will provide similar coverage available from the GPS satellites.

4.0 Applications.

Surface applications of DGPS include many public safety applications such as locating fire hydrants, performing search and rescue (SAR), finding addresses, and monitoring natural resources. Figure E-8 is an example of how important this is. Many state and local governments are beginning to use post processed DGPS information to locate rural and urban residences for use with enhanced 911 (E911) services. When DGPS services are available real-time, emergency services will be able to respond faster, saving lives and property. At some point in the near future, the question will be “Can we navigate to your coordinates?”

Figure E-8. The problem with rural addressing

In order to ensure that coverage is provided for these applications it is vital that corrections are as available as the standard positioning service (SPS) of GPS. This means the signal must not be obscured by either man made or natural barriers.

5.0 Conclusions

Geostationary Satellites, due to the necessary elevation angles, terrain obscuration, building obscuration, and tree canopy fading, do not provide sufficient coverage for surface applications to be a reliable source of DGPS corrections.