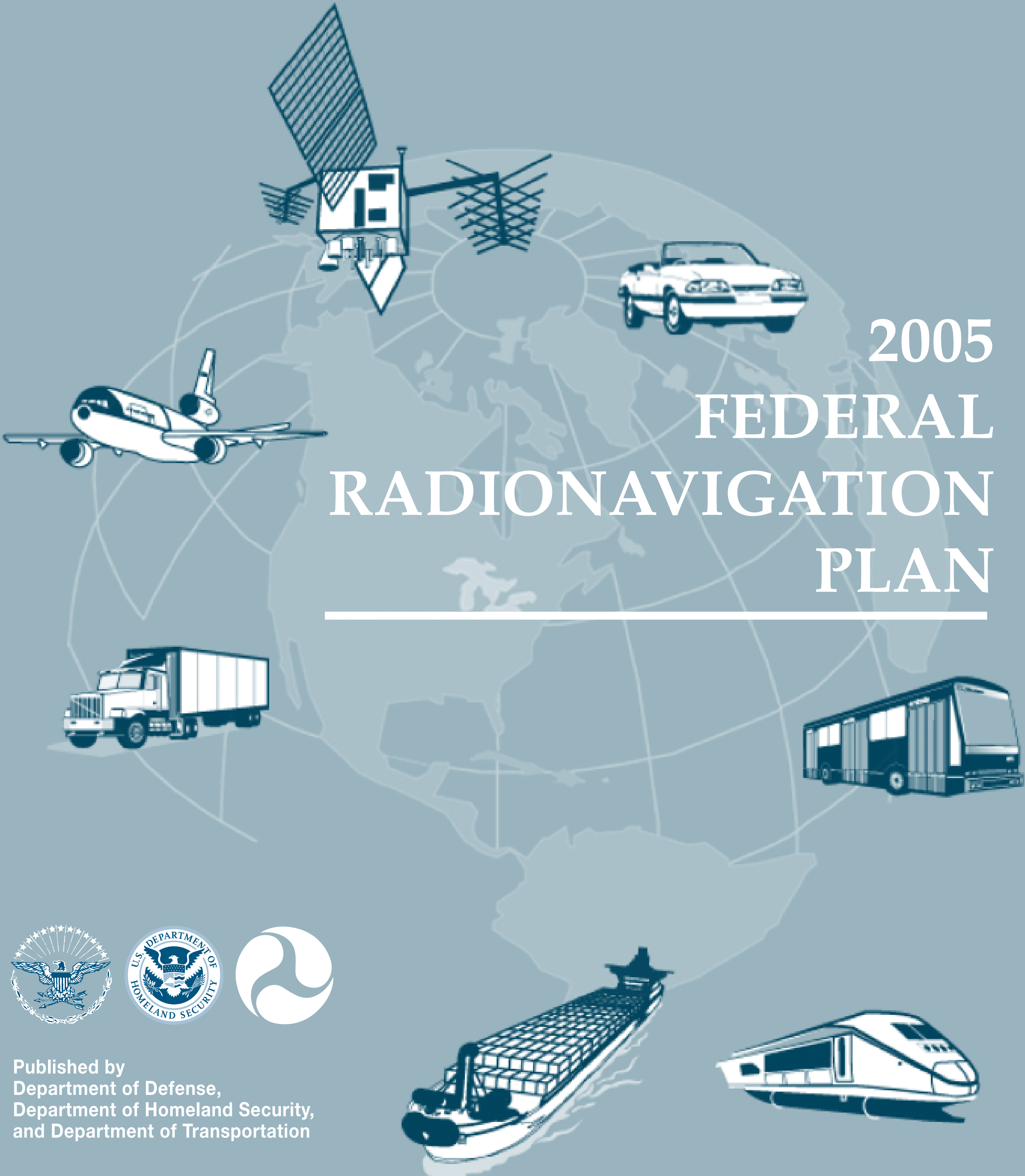

2005 FEDERAL RADIONAVIGATION PLAN

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2005 Federal Radionavigation Plan

The *Federal Radionavigation Plan* (FRP) is the official source of radionavigation policy and planning for the Federal Government, as directed by the National Defense Authorization Act for Fiscal Year 1998 (10 U.S.C. 2281(c)). It is prepared jointly by the Departments of Defense (DoD), Transportation (DOT), and Homeland Security (DHS) with the assistance of other government agencies. This edition of the FRP updates and replaces the 2001 FRP and covers common-use radionavigation systems (i.e., systems used by both civil and military sectors). Systems used exclusively by the military are covered in the Chairman, Joint Chiefs of Staff (CJCS) Master Positioning, Navigation, and Timing Plan (MPNTP).

The FRP includes an introduction, and sections on policies, operating plans, and research and development and will permit more efficient and responsive updates of policy and planning information. The companion document entitled, Federal Radionavigation Systems (FRS) includes government roles and responsibilities, user requirements, and systems descriptions. The FRS is periodically updated as necessary.

Your suggestions for the improvement of future editions are welcomed. Inputs may be submitted to Mr. Mike Shaw, DOT Positioning and Navigation Working Group Chair, at (202) 366-0353, Office of the Assistant Secretary for Transportation Policy, Washington, DC 20590.

Norman Y. Mineta Secretary of Transportation	Donald H. Rumsfeld Secretary of Defense	Michael Chertoff Secretary of Homeland Security
Date: OCT. 21, 2005	Date: JAN 15 2006	Date: 10/10/05

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- Global Positioning System (GPS)
- Augmentations to GPS
- Loran-C
- VOR and DME
- Tactical Air Navigation (TACAN)
- Instrument Landing System (ILS)
- Microwave Landing System (MLS)
- Aeronautical Nondirectional Radiobeacons (NDB)

The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the United States. It is a goal of the Government to provide this service in a cost-effective manner. The Department of Transportation (DOT) is responsible under Title 49 United States Code (U.S.C.) Section 101 for ensuring safe and efficient transportation. The Department of Defense (DoD) is responsible for maintaining aids to navigation required exclusively for national defense. The DoD is also required by 10 U.S.C. 2281(b) (Ref. 1) to provide for the sustainment and operation of GPS for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees.

A major goal of the DoD and the DOT is to ensure that a mix of common-use (civil and military) systems is available to meet user requirements for accuracy, reliability, availability, continuity, integrity, coverage, operational utility, and cost; to provide adequate capability for future growth; and to eliminate unnecessary duplication of services. Selecting a future radionavigation systems mix is a complex task, since user requirements vary widely and change with time. While all users require services that are safe, readily available and easy to use, the military has more stringent requirements including performance under intentional interference, operations in high-performance vehicles, worldwide coverage, and operational capability in severe environmental conditions. Cost is always a major consideration that must be balanced with a needed operational capability.

As the full civil potential of GPS and its augmentations is realized, the services provided by other Federally provided radionavigation systems may be phased down to match the reduction in demand, provided those services are not a part of a back-up navigation strategy for critical applications or safety-of-life services.

The Federal Government conducts research and development (R&D) activities relating to Federally provided radionavigation systems and their worldwide use by the U.S. armed forces and the civilian community. Civil R&D activities focus mainly on enhancements of GPS for civil uses. Military R&D activities mainly address military mission requirements and national security considerations.

A detailed discussion of agencies' roles and responsibilities, user requirements, and system descriptions can be found in the companion document to the FRP entitled *Federal Radionavigation Systems (FRS).*

The FRP is composed of the following sections:

Section 1 - Introduction to the Federal Radionavigation Plan: Delineates the purpose, scope and objectives of the plan and presents the DoD, DOT, and other Federal agencies' roles and responsibilities for providing radionavigation services. In addition, Section 1 discusses radionavigation system selection considerations.

Section 2 - U.S. Policies for Radionavigation Systems: Describes the U.S. policy for providing each Federal radionavigation system identified in this document.

Section 3 - Operating Plans for Radionavigation Systems: Summarizes the plans of the Federal Government to provide general-purpose and special-purpose radio aids to navigation for use by the civil and military sectors.

Section 4 - Research and Development Summary: Presents the research and development efforts planned and conducted by DoD, DOT, DHS, and other Federal organizations.

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1

Introduction to the Federal Radionavigation Plan

This section describes the background, purpose, and scope of the Federal Radionavigation Plan (FRP). It summarizes the events leading to the preparation of this document, the national objectives for coordinating the planning of radionavigation services, and radionavigation authority and responsibility.

1.1 Background

The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, prepared in response to the International Maritime Satellite (INMARSAT) Act of 1978. It marked the first time that a joint Department of Transportation (DOT) and Department of Defense (DoD) plan for radionavigation systems had been developed. Now, this biennially updated plan serves as the planning and policy document for all present and future Federally provided radionavigation systems. With the transfer of the United States Coast Guard (USCG) from DOT into the Department of Homeland Security (DHS) through PL 107-296 (116 Stat. 2135), this edition of the FRP marks the first time the document has been signed by the Secretaries of Defense, Transportation, and Homeland Security.

A Federal Radionavigation Plan is required by 10 United States Code (U.S.C.) 2281(c) (Ref. 1). A Memorandum of Agreement (MOA) (Ref. 2) between DoD and DOT provides for radionavigation planning as well as for the development and publication of the FRP. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. In addition, a Memorandum of Agreement (Ref. 3) between the

DoD and DOT on the civil use of the Global Positioning System (GPS) establishes policies and procedures to ensure an effective working relationship between the two Departments regarding the civil use of GPS.

1.2 Purpose

The purpose of the FRP is to:

- Present the current U.S. Government policy and plan for operating civil and military radionavigation systems.
- Outline the Government's approach for implementing new and consolidating existing radionavigation systems.
- Provide government radionavigation system planning information and schedules.
- Identify or clarify dual-use (i.e., used by both civil and military) radionavigation system issues.

1.3 Scope

This plan covers Federally provided radionavigation systems. The plan does not include systems that mainly perform surveillance and communication functions.

The systems addressed in this FRP are:

- Global Positioning System (GPS)
- Augmentations to GPS (See Section 2.2.2)
- Loran-C
- Tactical Air Navigation (TACAN)
- Instrument Landing System (ILS)
- Microwave Landing System (MLS)
- Aeronautical Nondirectional Beacons (NDB)
- Very High Frequency (VHF) Omnidirectional Range (VOR) and Distance Measuring Equipment (DME)

1.4 Objectives

The objectives of U.S. Government radionavigation system policy are to:

- Strengthen and maintain national security.
- Provide safety of travel.
- Promote efficient transportation.

- Promote increased transportation capacity and mobility.
- Help protect the environment.
- Contribute to the economic growth, trade, and productivity of the United States.

1.5 Authority to Provide Radionavigation Services

The DOT is responsible under Title 49 United States Code Section 101 for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The three civil Federal elements that operate radionavigation systems are the Federal Aviation Administration (FAA), the St. Lawrence Seaway Development Corporation (SLSDC), and the USCG that is now within the DHS. Although USCG is now a DHS component, its underlying authorities to establish, maintain, and operate aids to navigation, including 14 U.S.C. §81, remain in full effect. The DOT Assistant Secretary for Transportation Policy (OST/P) is responsible for coordinating radionavigation planning within DOT and with other civil Federal elements.

The USCG provides U.S. aids to navigation for safe and efficient marine navigation. The FAA has the responsibility for the development and implementation of radionavigation systems to meet the needs for safe and efficient air navigation, as well as for control of all civil and military aviation in the National Airspace System (NAS). The FAA also has the responsibility to operate aids to air navigation required by international treaties. The SLSDC provides navigation aids in U.S. waters in the St. Lawrence River and operates a Vessel Traffic Control System with the St. Lawrence Seaway Management Corporation of Canada.

Several elements within DOT also participate in radionavigation planning. These elements include the Maritime Administration (MARAD), the Federal Highway Administration (FHWA), the Intelligent Transportation Systems Joint Program Office (ITS-JPO), the Federal Railroad Administration (FRA), the National Highway Traffic Safety Administration (NHTSA), the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA), and the Research and Innovative Technology Administration (RITA). Other Federal agencies that participate in radionavigation planning include the DHS, the National Aeronautics and Space Administration (NASA), and the National Geodetic Survey/National Oceanic and Atmospheric Administration/Department of Commerce (NGS/NOAA/DOC).

The DoD is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required solely for national defense. DoD is also responsible for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigation capabilities.

The DoD is also required by 10 U.S.C. 2281(b) (Ref. 1) to provide for the sustainment and operation of the GPS Standard Positioning Service (SPS) for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees. The DoD is also required to provide for the sustainment and operation of the GPS Precise Positioning Service (PPS). A detailed discussion of U.S. Government agency roles and responsibilities is contained in the companion *Federal Radionavigation Systems (FRS)* document (Ref. 4).

1.6 Radionavigation System Selection Considerations

Many factors are considered in determining the optimum mix of Federally provided radionavigation systems. These factors include operational, technical, economic, institutional, radio frequency spectrum, needs of national defense, and international parameters. Important technical parameters include system accuracy, integrity, coverage, continuity, availability, reliability, and radio frequency spectrum. Certain unique parameters, such as anti-jamming performance, apply principally to military needs but can also affect civil availability.

The current investment in ground and user equipment must also be considered. In some cases, there may be international commitments that must be honored or modified in a fashion mutually agreeable to all parties.

In most cases, the systems that are currently in place today were developed to meet different user requirements. This resulted in the proliferation of multiple radionavigation systems and was the impetus for early radionavigation planning. The first edition of the FRP was published to plan the mix of radionavigation systems and promote an orderly life cycle for them. It described an approach for selecting radionavigation systems to be used in the future. Early editions of the FRP, including the 1984 edition, reflected that approach with minor modifications to the timing of events. By 1986, it became apparent that a final recommendation on the future mix of radionavigation systems was not appropriate and major changes to the timing of system life-cycle events were required. Consequently, it was decided that starting with the 1986 FRP, an updated recommendation on the future mix of radionavigation systems would be issued with each edition of the FRP. The 2005 FRP reflects policy direction from the 2004 U.S. Space-Based Positioning, Navigation, and Timing Policy (Ref. 5), dynamic radionavigation technology, changing user profiles, budget considerations, international activities and input received at radionavigation user conferences sponsored by DOT and DoD. With the creation of the Department of Homeland Security, the DOT and DoD will maintain the current working relationship with the United States Coast Guard via Memoranda of Agreement.

In the final analysis, provision of Government services for meeting user requirements is subject to the budgetary process, including authorizations and appropriations by Congress, and priorities for allocations among programs by agencies.

When, after appropriate analysis and study, the need or economic justification for a particular system or capability appears to be diminishing, the Department operating the system will notify the appropriate Federal agencies and the public, by publishing the proposed discontinuance of service in the Federal Register.

1.6.1 Operational Considerations

1.6.1.1 Military Selection Factors

Operational requirements determine DoD's selection of radionavigation systems. Precise positioning, navigation and timing (PNT) information is a key enabler for a variety of systems and missions. In conducting military operations, it is essential that PNT services be available with the highest possible confidence. These services must meet or exceed mission requirements. In order to meet these mission requirements, military operators may use a mix of independent, self-contained, and externally referenced PNT systems provided that these systems can be traced directly to the DoD reference standards WGS-84 (World Geodetic System 1984) and UTC (Coordinated Universal Time)/USNO (U.S. Naval Observatory). Only DoD approved PNT systems will be used for combat, combat support, and combat service support operations. Factors for military selection of radionavigation systems include, but are not limited to:

- Flexibility to accommodate new weapon systems and technology.
- Resistance to intentional or unintentional interference or degradation.
- Interoperability with DoD systems and allies' systems to support coalition operations.
- Position and time accuracy relative to common grid and time reference systems, to support strategic and tactical operations.
- Availability of alternate means of obtaining positioning, navigation, and timing data.
- Worldwide mobility requirements.
- Compatibility with civil systems and operations.

Military-specific selection criteria may be found in the Chairman of the Joint Chiefs of Staff Instruction 6130.01C, CJCS Master Positioning, Navigation, and Timing Plan (Ref. 6).

1.6.1.2 Civil/Military Compatibility

DoD aircraft, vehicles, and ships operate in civil environments. Accordingly, they may utilize civil PNT systems consistent with DoD policy in peacetime scenarios as long as the systems in use meet International Maritime Organization (IMO), International Civil Aviation Organization (ICAO), or FAA specifications. Civil PNT systems are not intended for combat, combat support, or combat service support operations. In some cases, when it is appropriate, there are potential cost advantages in the development of common civil/military systems.

1.6.1.3 Review and Validation

The DoD radionavigation system requirements review and validation process:

- Identifies the unique components of mission requirements.
- Identifies technological deficiencies.
- Determines, through interaction with DOT and DHS, the impact of new military requirements on the civil sector.
- Investigates system costs, user populations, and the relationship of candidate systems to other systems and functions.

1.6.2 Technical Considerations

In evaluating future radionavigation systems, there are a number of technical factors that must be considered:

- Received signal strength
- Spectrum availability
- Multipath effects
- Signal accuracy
- Signal acquisition and tracking continuity
- Signal integrity
- System availability
- Signal continuity
- Vehicle dynamic effects
- Signal coverage
- Noise effects
- Signal propagation
- Susceptibility to natural or man-made radio frequency interference (RFI)
- Installation requirements
- Environmental effects
- Human factors engineering
- Reliability

1.6.2.1 *Vulnerability of GPS in the National Transportation Infrastructure*

The Final Report of the President's Commission on Critical Infrastructure Protection concluded that GPS services and applications are susceptible to various types of radio frequency interference, and that the effects of these vulnerabilities on civilian transportation applications should be studied in detail. As a result of the report, Presidential Decision Directive 63 gave the Department of Transportation the following directive:

> The Department of Transportation, in consultation with the Department of Defense, shall undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on the Global Positioning System. This evaluation shall include sponsoring an independent, integrated assessment of risks to civilian users of GPS-based systems, with a view to basing decisions on the ultimate architecture of the modernized NAS on these evaluations.

The Volpe National Transportation Systems Center (Volpe Center) conducted this evaluation and identified GPS vulnerabilities and their potential impacts to aviation, maritime transportation, railroads, highway, and non-positioning systems. The final report, *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System* (Ref. 7), was published on September 10, 2001 and is available on the Coast Guard Navigation Center website www.navcen.uscg.gov. The report's main conclusion is that GPS has vulnerabilities for civilian users of the national transportation infrastructure. The report also states that care must be taken to ensure that adequate back-up systems or procedures can be used when needed.

The Volpe report offered several key recommendations for improving the safety and efficiency of the national transportation infrastructure while preserving security by ensuring back-up systems and operating procedures in the event of loss of GPS service. The Secretary of Transportation accepted the recommendations contained in the report and requested each modal Administrator to develop plans for mitigating the risks associated with loss of GPS services.

The 2004 U.S. Space-Based Positioning, Navigation, and Timing Policy states that GPS shall be maintained as a component of multiple sectors of the U.S. Critical Infrastructure, consistent with Homeland Security Presidential Directive-7. It also defines responsibilities for locating and resolving interference. The mitigation of disruptions to satellite-based navigation services is discussed in Section 3.3.

1.6.3 *Economic Considerations*

The Government must continually review the costs and benefits of the navigation systems or capabilities it provides. This continuing analysis can be used both for setting priorities for investment in new systems, and determining the appropriate mix of older systems to be retained. In some cases, the older systems will have to be retained for safety reasons and to allow adequate time for the transition to newer more accurate systems and user equipment; however, older systems must be periodically evaluated to determine whether the systems are needed or are cost effective.

In many instances, aids to air navigation that do not economically qualify for ownership and operation by the Federal Government are needed by private, corporate, or state organizations. While these non-Federally owned/operated systems do not provide sufficient economic benefit on a national scale, they may provide significant economic benefit to specific user groups or local economies. In most cases they are also available for public use. The FAA regulates and inspects aviation facilities in accordance with Federal Aviation Regulations, Title 14 Part 171 of the Code of Federal Regulation (CFR) Non-Federal Navigation Facilities, and FAA directives.

1.6.4 Institutional Considerations

1.6.4.1 Cost Recovery for Radionavigation Services

In accordance with general policy and the User Fee Statute, 31 U.S.C., 9701, the U.S. Government recovers the costs of Federally provided services that provide benefits to specific user groups. The amount of use of present Federal radionavigation services by individual users or groups of users cannot be easily measured; therefore, it would be difficult to apportion direct user charges. Cost recovery for radionavigation services is either through general tax revenues or through transportation trust funds, which are generally financed with indirect user fees. In the case of GPS, the 2004 U.S. Space-Based Positioning, Navigation, and Timing Policy states that GPS civil services and GPS augmentations shall be provided free of direct user fees. In the case of Nationwide Differential GPS (NDGPS), Public Law 105-66 Section 346 authorizes the Secretary of Transportation to manage and operate the NDGPS and ensure that the service is provided without the assessment of any user fee.

1.6.4.2 Signal Availability

The availability of accurate navigation signals at all times is essential for safe navigation. Conversely, guaranteed availability of optimum performance may diminish national security objectives, making contingency planning necessary. The U.S. national policy is that all radionavigation systems operated by the U.S. Government will remain available for peaceful use subject to direction by the President in the event of a war or threat to national security.

In order to minimize service disruptions and prevent situations threatening safety or efficient use of GPS, any government agency or activity with a need to perform interference testing (i.e., transmit) in the GPS spectrum must coordinate with the FAA Spectrum Policy and Management Office. The FAA Spectrum Policy and Management Office coordinates all GPS interference testing to ensure minimal impact to non-participating DoD and DOT mission critical activities. The DoD is the principal Federal agency conducting deliberate interference testing on GPS frequencies. The Joint Staff publishes instructions for the coordination of Electronic Attack testing on these frequencies. As such, DHS, in coordination with DOT and DoD, and in cooperation with other Departments and Agencies, coordinates the use of Federal capabilities and resources to identify, locate, and attribute any interference within the United States that adversely affects GPS and its augmentations.

1.6.4.3 Role of the Private Sector

Radionavigation systems have historically been provided by the Government to support safety, security, and commerce. These services have supported air, land and marine navigation and timing or frequency-based services, surveying, mapping, weather forecasting, precision farming, and scientific applications. For certain applications such as landing, positioning, and surveying, in areas where Federal systems are not justified, a number of privately operated systems are available to the user as an alternative.

Air navigation facilities, owned and operated by non-Federal service providers, are regulated by the FAA under Title 14 Part 171 of the CFR "Non-Federal Navigation Facilities." A non-Federal sponsor may coordinate with the FAA to acquire, install and turn an air navigation facility over to the FAA for maintenance because waiting for a Federally provided facility would cost too much in lost business opportunity. Non-Federal facilities are operated and maintained to the same standards as Federally operated facilities under an Operations and Maintenance Manual agreement with the FAA. This program includes recurrent ground and flight inspections of the facility to ensure that it continues to be operated in accordance with this agreement.

A number of factors need to be considered when examining private sector involvement in the provision of air navigation services:

- Consideration of phase-over to private operation as a viable alternative to phase out of a Federally operated radionavigation service.
- Private sector development of air navigation facilities for both Federal and non-Federal use.
- Impact of privately operated services on usage and demand for Federally operated services.
- Need for a Federally provided safety of navigation service even if commercially provided services are available.
- Liability considerations for the developer, service provider, and user.
- Radio frequency spectrum issues.
- Certification of the equipment, service, service provider, operator, and controller.

1.6.5 International Considerations

Radionavigation services and systems consider the standards and guidelines of international groups, including the North Atlantic Treaty Organization (NATO) and other allies, ICAO, the International Telecommunication Union (ITU), and the IMO.

The goals of performance, standardization, and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. The ICAO establishes standards for internationally used civil aviation radionavigation systems. The IMO plays a similar role for the international maritime community. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) also develops international radionavigation guidelines. IMO reviews existing and proposed radionavigation systems to identify systems that could meet the requirements of, and be acceptable to, members of the international maritime community.

In planning U.S. radionavigation systems, consideration is also given to the possible future use of internationally shared systems. In addition to operational, technical, and economic factors, international interests must also be considered in the determination of a system or systems to best meet civil user needs. International negotiations and consultations occur under the auspices of the Department of State.

1.6.6 Interoperability Considerations

Radionavigation systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented to provide improved or complementary performance. In the case of GPS, the U.S. Government encourages future interoperability with foreign space-based PNT systems for civil, commercial, and scientific uses worldwide. Examples of existing or future foreign space-based PNT systems are Russia's Global Navigation Satellite System (GLONASS), European Union's Galileo, and Japan's Quasi Zenith Satellite System. Properly designed receivers that take advantage of these systems may benefit from additional satellite signals, increased redundancy, and improved performance over that obtained from just one system alone. A critical aspect of system interoperability is ensuring compatibility among radionavigation services. For example, the U.S. Government has concerns about radionavigation signal structures that could adversely impact the military and civil use of GPS.

1.6.7 Radio Frequency Spectrum Considerations

Radionavigation services use a significant amount of radio frequency spectrum to provide the world with a safe and robust transportation system. Radionavigation services require sufficient bandwidth, an appropriate level of signal availability and integrity, and adequate protections from sources of interference. Spectrum engineering management is a key foundation for Federal Government radionavigation system policy, implementation and operation.

In planning for radionavigation systems and services, careful consideration must be made of the U.S. and international regulatory environments in terms of spectrum allocations and management. This is due to the continued trend toward spectrum sharing, where restricted bands could be subjected to unintentional RFI from incompatible radio services. For this reason, electromagnetic compatibility analysis remains a key requirement for planning and certification of radionavigation systems. Power levels, antenna height, channel spacing, total bandwidth, spurious and out-of-band emissions (OOBE) and geographic location must all be factored into implementing new systems, and ensuring adequate protection for existing services. Rights and responsibilities of primary and secondary allocation incumbents and new entrants are considered on specific, technically defined criteria.

Within the U.S., two regulatory bodies oversee the use of radio frequency spectrum. The Federal Communications Commission (FCC) is responsible for all non-Federal use of the airwaves, while the National Telecommunications and Information Administration (NTIA) manages spectrum use for the Federal Government. As part of this process, the NTIA hosts the Interdepartment Radio-Advisory Committee (IRAC), a forum consisting of Executive Branch agencies that act as service providers and users of Government spectrum, including safety-of-life bands. The FCC participates in IRAC meetings as an observer. National transportation spectrum policy is coordinated through the DOT Office of Navigation and Spectrum Policy, Office of the Secretary (OST), while spectrum for DoD is coordinated through the Assistant Secretary of Defense for Networks and Information Integration (NII).

The broadcast nature of radionavigation systems also provides a need for U.S. regulators to go beyond domestic geographic boundaries to coordinate with other nations through such forums as the International Telecommunication Union. The ITU is a specialized technical arm of the United Nations (UN), charged with allocating spectrum on a global basis through the actions of the World Radiocommunication Conference (WRC), held every 3-4 years. As a result of the WRC process, where Final Resolutions hold treaty status among participating nations, spectrum allocations stay relatively consistent throughout the world, and end users can use the same radionavigation equipment free from RFI regardless of where they operate.

Non-interference in transportation applications is crucial, as all domestic and international radionavigation services are dependent on the uninterrupted broadcast, reception and processing of radio frequencies in protected radio bands. Use of these frequency bands is restricted because stringent accuracy, availability, integrity, and continuity parameters must be maintained to meet service provider and end user performance requirements. Representatives from DoD, DOT, and DHS work with other government and private sector agents as members of the U.S. delegation to jointly advocate radionavigation requirements, and considerable effort is put forth to ensure that radionavigation services are protected throughout WRC deliberations. GPS is unique in that it is a space-based radionavigation system, and is thus protected under several allocation designations reflective of its myriad uses as a positioning, navigation, and timing service. The specific ITU band designations that define radionavigation services are listed below:

- Aeronautical Radionavigation Service (ARNS)
- Radiolocation Service (RLS)
- Radionavigation Satellite Service (RNSS)

- Radionavigation Service (RNS)

The certification and use of radionavigation services is the shared responsibility of the DOT, DHS, and DoD. The DOT, DHS, and DoD are Federal users of spectrum, as well as service providers and operators of radionavigation systems. Within DOT, the FAA use of spectrum is primarily in support of aeronautical safety services used within the NAS. Within DHS, the USCG uses spectrum to operate radionavigation systems used on waterways, specifically NDGPS and Loran-C.

Other DOT agencies (FRA, FHWA, FTA, and NHTSA) also work with private sector and state and local governments to use spectrum for Intelligent Transportation System (ITS) and Intelligent Railroad System applications. Many ITS applications will use GPS and other radiodetermination systems to make roadway travel safer and more efficient by providing differential corrections and location information in an integrated systems context. Intelligent Railroad System, Positive Train Control, Rail Defect Detection, and Automated Rail Surveying rely on NDGPS and rail industry telecommunications frequencies to improve safety, efficiency, and effectiveness. Spectrum used for the transportation, military, and homeland security applications must remain free from interference due to public safety requirements.

2

U.S. Policies for Radionavigation Systems

This section sets forth the policy for Federally provided radionavigation systems.

2.1 General

The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the United States. A goal of the Government is to provide radionavigation services to the public in the most cost-effective manner possible.

As the full civil potential of GPS services and its augmentations are implemented, the demand for services provided by other Federally provided radionavigation systems is expected to decrease. The Government will reduce non-GPS-based radionavigation services with the reduction in the demand for those services. However, it is the policy of the U.S. Government not to rely on a single system for positioning, navigation, and timing. The U.S. Government will maintain back-up capabilities to meet (1) growing national, homeland, and economic security requirements, (2) civil requirements, and (3) commercial and scientific demands. Operational, safety, and security considerations will dictate the need for complementary navigation systems to support navigation or conduct certain operations. While some operations may be conducted safely using a single radionavigation system, it is Federal policy to provide redundant radionavigation service where required. Backups to GPS for safety-of-life navigation applications, or other critical applications, can be other radionavigation systems, or operational procedures, or a combination of these systems and procedures to form a safe and effective backup. Backups to GPS for timing applications can be a highly accurate crystal oscillator or atomic clock and a communications link to a timing source that is traceable to UTC.

When the benefits, including the safety benefits, derived by the users of a service or capability are outweighed by its cost, the Federal Government should no longer continue to provide that service or capability. A suitable transition period will be established prior to decommissioning of Federal radionavigation services, based on factors such as user equipment availability, radio spectrum transition issues, cost, user acceptance, budgetary considerations, and the public interest. International commitments will affect certain types and levels of navigation services provided by the Federal Government to ensure interoperability with international users.

Radionavigation systems established primarily for safety of transportation and national defense also provide significant benefits to other civil, commercial, and scientific users. In recognition of this, the Federal Government will consider the needs of these users before making any changes to the operation of radionavigation systems.

The U.S. national policy is that all radionavigation systems operated by the U.S. Government will remain available for peaceful use subject to direction by the President in the event of a war or threat to national security. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency. All communications links, including those used to transmit differential GPS corrections and other GPS augmentations, are also subject to the direction of the President.

2.2 Individual Systems

2.2.1 GPS

GPS is a multi-use, space-based radionavigation system owned by the U.S. Government, and operated by the DoD, to meet National and homeland security, civil, commercial, and scientific needs. The U.S. Space-based PNT Policy established a new National Space-based PNT Executive Committee (National PNT EXCOM) co-chaired by the Deputy Secretaries of the Department of Defense and Transportation. The National PNT EXCOM will make recommendations to its member Departments and Agencies, and to the President through the representatives of the Executive Office of the President, advise and coordinate on strategic decisions regarding policies, architectures, requirements, and resource allocation for GPS and its augmentations. Its function is to ensure that national security, homeland security, and civil requirements receive full and appropriate consideration in Department decision-making processes. This new structure is intended to ensure that civil, as well as military, needs are properly considered in the future development and modernization of GPS. The National PNT EXCOM replaced the Interagency GPS Executive Board.

The GPS provides two levels of service: SPS which uses the coarse acquisition (C/A) code on the L1 frequency, and PPS which uses the P(Y) code on both the L1 and L2 frequencies. Access to the PPS is restricted to U.S. armed forces, U.S. Federal agencies, and selected allied armed forces and governments. These restrictions are based on U.S. national security considerations. The SPS is available to all users on a continuous, worldwide basis, free of any direct user charge.

The specific capabilities provided by SPS are published in the *Global Positioning System Standard Positioning Service Performance Standard* (Ref. 8) available on the Coast Guard Navigation Center website: www.navcen.uscg.gov.

The National Geospatial-Intelligence Agency (NGA) determines the post-fit GPS precise ephemeris which is considered DoD truth. NGA operates a global network of 11 GPS monitor stations geographically placed to complement the Air Force monitor stations. NGA stations are well controlled with complete redundancy in key components and provide high quality data. NGA also provides products for positioning, navigation, and timing. GPS products from NGA can be found at http://earth-info.nga.mil/GandG/sathtml.

The U.S. Government has determined that two additional coded civil signals are required for certain civilian applications. A second civil signal will be added at the GPS L2 frequency designated as L2C. A third civil signal will also be added at 1176.45 MHz to meet the needs of critical safety-of-life applications such as civil aviation. The third civil signal is designated as L5.

GPS will be the primary Federally provided radionavigation system for the foreseeable future.

GPS will be augmented and improved to satisfy future military and civil requirements for accuracy, coverage, availability, continuity, and integrity.

2.2.2 Augmentations to GPS

Nationwide Differential GPS (NDGPS): The NDGPS provides increased accuracy and integrity of the GPS using land-based reference stations that transmit correction messages. The maritime portion of the NDGPS provides service for coastal coverage of the conterminous U.S. (CONUS), the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. The U.S. is expanding the NDGPS to cover all surface areas of the United States to meet the requirements of surface users.

Wide Area Augmentation System (WAAS): The WAAS, a satellite-based augmentation system (SBAS) operated by the FAA, supports aircraft navigation during departure, en route, arrival, and approach operations. WAAS is also used to support FAA safety, capacity, and efficiency initiatives. These initiatives include more efficient use of airspace, improved procedures, and better situational awareness during ground operations. WAAS is also used in many other civil applications.

National Continuously Operating Reference Stations (CORS): The national CORS is a GPS augmentation system managed by NOAA that archives and distributes GPS data for precision positioning and atmospheric modeling applications. It serves as the basis for the National Spatial Reference System, defining high accuracy coordinates for all CONUS-based Federal radionavigation systems. Historically, CORS served post-processing users of GPS, but is being modernized to support real-time users at a similar level of accuracy.

Global Differential GPS (GDGPS): GDGPS is a high accuracy GPS augmentation system, developed by Caltech's Jet Propulsion Laboratory (JPL), to support the real-time positioning, timing, and determination requirements of NASA's science mission. GDGPS offers a host of real-time and near-time products. The following products are freely available to the public: raw data from the GDGPS tracking network (hourly), sea surface height from the Jason ocean altimetry satellite (approximately every 3 hours), images of the global distribution of ionospheric total electron content (real-time) and, finally, GPS constellation status, global performance metrics, and situational assessment (real-time). Additional information may be obtained from the GDGPS website: http://www.gdgps.net. GDGPS also contributes data to the International GNSS Service (IGS). IGS is a service that provides the highest quality data and products in support of Earth science research, multidisciplinary applications, and education, as well as to facilitate other applications benefiting society. IGS advocates an open data, and equal access, policy.

2.2.3 Loran-C

Loran-C is a stand-alone, hyperbolic radionavigation system that provides horizontal coverage throughout the 48 conterminous states, their coastal areas, and most of Alaska south of the Brooks Range. It supports positioning, navigation, and timing services for air, land, and marine users.

The Government continues to operate the Loran-C system in the short term while evaluating the long-term need for the system. If a decision is made to discontinue Loran as a result of these evaluations, then at least six months notice will be provided to the public prior to the termination of service.

2.2.4 VOR/DME

VOR/DME provides users with a means of air navigation in the NAS. VOR/DME will continue to provide navigation services for en route through nonprecision approach phases of flight throughout the transition to satellite-based navigation. The FAA plans to reduce VOR services provided in the NAS based on the anticipated decrease in use of VOR for en route navigation and instrument approaches.

The FAA plans to install additional low-power DMEs to support ILS precision approaches as recommended by the Commercial Aviation Safety Team. The FAA may also need to sustain, modify or expand the existing DME services to provide a redundant area navigation (RNAV) capability for terminal area operations at major airports and to provide continuous coverage for RNAV operations at en route altitudes.

2.2.5 TACAN

TACAN is the military counterpart of VOR/DME. It is an airborne, ground- or ship-based radionavigation system that combines the bearing capability of VOR and the distance-measuring function of DME. The azimuth service of TACAN primarily serves military users whereas the DME serves both military and civil users. The DoD requirement and use of land-based TACAN will continue until aircraft are properly integrated with GPS, and GPS-PPS is approved for all appropriate operations in national and international controlled airspace.

2.2.6 ILS

The Instrument Landing System is the predominant system supporting precision approaches in the U.S. With the advent of GPS-based precision approach systems, the role of Category I ILS will be reduced. ILS will continue to provide precision approach service at major terminals.

2.2.7 MLS

The FAA has terminated the development of the Microwave Landing System and does not anticipate installing additional MLS equipment in the NAS. MLS service is expected to be phased out beginning in 2010.

2.2.8 Aeronautical Nondirectional Beacons (NDB)

NDBs serve as nonprecision approach aids at some airports. They are also used as compass locators, generally collocated with the outer marker of an ILS, and are used as en route navigation aids. The role of NDBs will be reduced. Most NDBs will be phased out with the exception of those that serve International Gateways, and within Alaska. Some NDBs may also be retained where required to provide guidance for missed approach procedures.

2.2.9 Marker Beacons

Marker beacons provide audible and visual identification of positions along the final approach path of a precision instrument approach. The FAA intends to phase down marker beacons in favor of using published distances to a DME facility or establishing navigation waypoints collocated with the existing marker beacon facilities that will enable aircraft to determine progress along the approach to a runaway.

3

Operating Plans for Radionavigation Systems

This section summarizes the plans of the Federal Government to provide radionavigation systems and services for use by the civil and military sectors. It focuses on three aspects of planning: (1) the efforts needed to maintain existing systems in a satisfactory operational configuration; (2) the development needed to improve existing system performance or to meet unsatisfied user requirements in the near term; and (3) the evaluation of existing and proposed radionavigation systems to meet future user requirements. Thus, the plan provides the framework for operation, development, and evolution of systems.

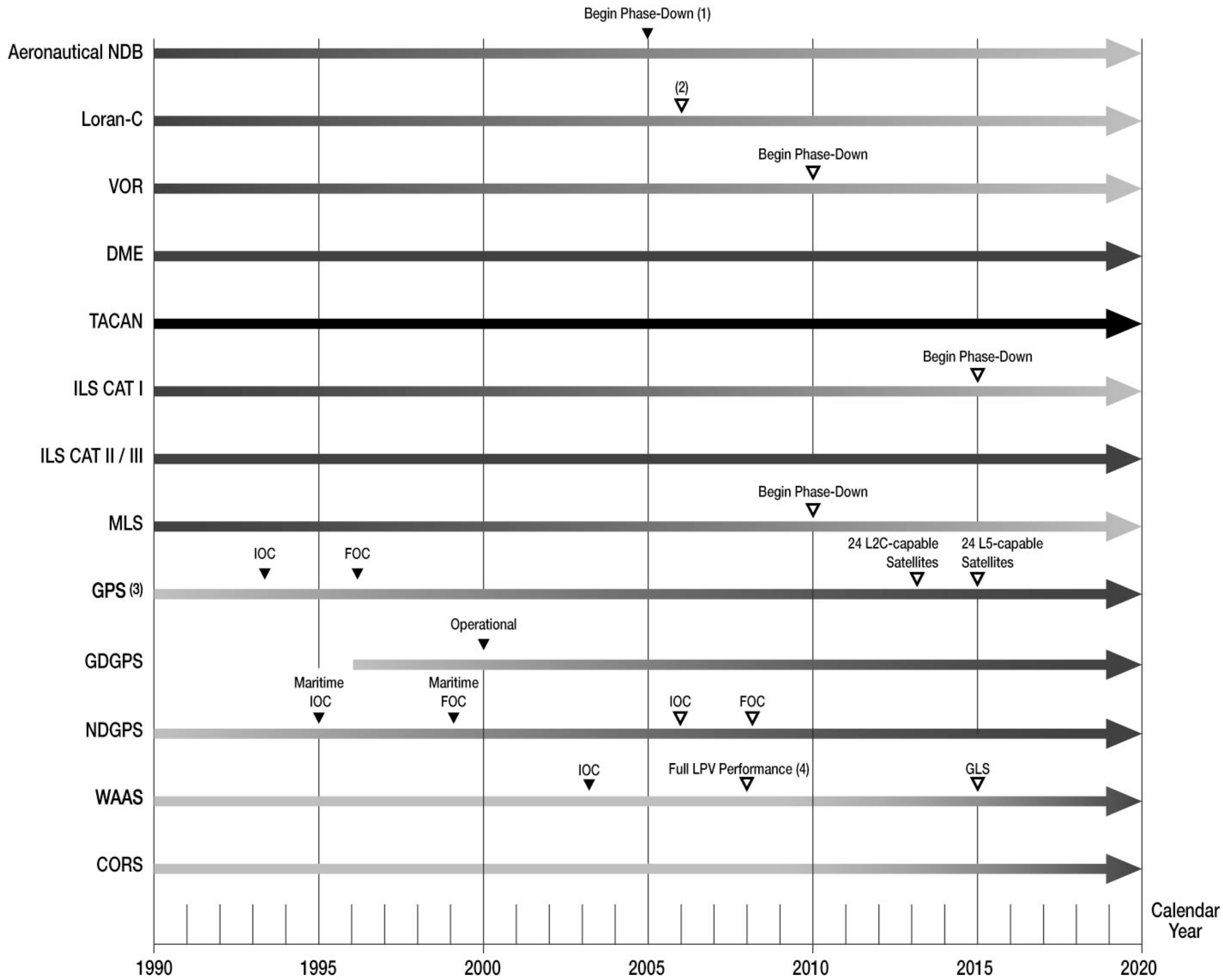
3.1 Operating Plans

Figure 3-1 shows the operating plans for Federally provided common-use radionavigation systems.

3.1.1 Global Positioning System (GPS)

The DoD will maintain a nominal 24-satellite constellation. Replacement satellites will be launched on an anticipated need to maintain the constellation as satellites age and ultimately fail.

The DoD will provide a 48-hour advance notice of changes in the constellation operational status that affect the service being provided to GPS SPS users in peacetime, other than planned GPS interference testing. DoD will also provide 48-hour notice of any planned periods for which GPS will not be capable of providing SPS as specified in the



(1) Service will be retained in Alaska, in certain offshore areas, and for international gateways.
(2) Operation beyond 2006 depends upon further analysis by DHS.
(3) Planned dates-reference current planning documents for GPS.
(4) The end of development activities associated with WAAS single-frequency performance.

Figure 3-1. Radionavigation Systems Operating Plan

GPS Standard Positioning Service Performance Standard (Ref. 8).

Coordination of planned interference testing activities nominally begins 60 days before testing events. Users are notified by the USCG as soon as an activity is approved, and by the FAA typically not earlier than 72 hours before an activity begins. The DoD notice will be given to the USCG Navigation Information Service (NIS) and the FAA Notice to Airmen (NOTAM) system. The NIS and NOTAM systems will announce unplanned system outages resulting from system malfunctions or unscheduled maintenance.

3.1.2 GPS Modernization

The GPS Modernization effort focuses on improving position and timing accuracy, availability, integrity monitoring support capability and enhancement to the operational control segment. As these system enhancements are introduced, users will be able to continue to use existing IS-GPS-200 (Ref. 9) compliant receivers, as signal backward compatibility is a requirement for both the military and civil user communities. Although current GPS users will be able to operate at the same, or better, levels of performance that they enjoy today, users will need to modify existing user equipment or procure new user equipment in order to take full advantage of any new signal structure enhancements.

GPS modernization is a multi-phase effort to be executed over the next 15 or more years. Additional signals are planned to enhance the ability of GPS to support civil users and provide a new military code. The first new signal will be the new civil code on the L2 frequency (L2C - 1227.60 MHz). This signal, designated L2C, will enable dual-frequency code-based civil receivers to correct for ionospheric error. A third civil signal will be added on the L5 frequency (1176.45 MHz) for safety-of-life applications and other applications as appropriate. L5 can serve as a complementary signal to the GPS L1 frequency (1575.42 MHz) with a goal of assurance of continuity of service potentially to provide precision approach capability for aviation users. In addition, a secure and spectrally separated Military Code (M-Code) will be broadcast on the L1 and L2 frequencies. The first launch of an L2C capable satellite is scheduled for 2005, and the first launch of a L5 capable satellite is scheduled for 2007. Twenty-four L2C capable GPS satellites are projected to be on orbit by approximately 2013, and 24 GPS L5 capable satellites are projected to be on orbit by approximately 2015. Prior to declaration of Full Operational Capability (FOC), not all performance parameters of the new civil signals will be met, and therefore the new signals will be available to users at their own risk.

3.1.3 **Augmentations to GPS**

GPS SPS does not meet all the different user performance requirements for civil navigation, positioning, and timing applications.

Various differential techniques are used to augment the GPS to meet specific user performance requirements. However, it is important to note that civil differential systems and users of civil differential systems are dependent upon being able to receive the GPS civil signal in order to compute a position using differential techniques.

3.1.3.1 Nationwide Differential GPS (NDGPS)

The Coast Guard began development of a Maritime Differential GPS (MDGPS) system in the late 1980's to meet the needs of the Coastal and Harbor Entrance and Approach (HEA) phases of navigation and to enable automated buoy positioning. The MDGPS service was certified fully operational in March 1999 after the network met the performance standards required for HEA navigation. Public Law 105-66 section 346 (Ref. 10) authorized the improvement and expansion of the Coast Guard MDGPS system into a NDGPS system. Today, nine Federal agencies, several states, and scientific organizations are cooperating to complete the NDGPS system throughout the U.S.

NDGPS currently meets all of the MDGPS FOC performance requirements as declared in 1999. NDGPS also supports the CORS system for post-processing survey applications, the National Weather Service's Forecast Systems Laboratory for short-term precipitation forecasts, and the University NAVSTAR Consortium (UNAVCO) for plate tectonic monitoring. Additionally, where operational considerations allow, additional operational capability can be added, such as the broadcast of navigational or meteorological warnings and marine safety information (i.e., NAVTEX data) to support safe navigation at sea.

When complete, NDGPS will provide uniform coverage of the conterminous U.S., Hawaii, and Alaska, regardless of terrain, man-made obstructions, or other surface obstructions. This coverage is achieved by using a medium frequency broadcast optimized for surface applications. The broadcast has been demonstrated to be sufficiently robust to work throughout mountain ranges and other obstructions. Lastly, the completed NDGPS system will provide a highly reliable GPS integrity function to users that will enable applications such as Positive Train Control and precision agriculture throughout the U.S.

Initial Operating Capability (IOC) is defined as providing users with coverage by at least one NDGPS site over CONUS. FOC is defined as achieving dual coverage throughout CONUS. Based on currently planned funding levels, IOC is projected for 2006 and FOC is projected for 2009. As each new NDGPS site is added to the network, it is evaluated and tested to ensure that it meets the full operational capability specifications. Once a site is declared fully operational, the site is monitored and maintained by the USCG to ensure support for safety applications. The most up-to-date system coverage for a specific area can be obtained from the USCG Navigation Center website www.navcen.uscg.gov.

3.1.3.2 Wide Area Augmentation System (WAAS)

The WAAS, a satellite-based augmentation system operated by the FAA, provides increased navigation accuracy, availability, and integrity for aircraft operations. Although designed primarily for aviation users, WAAS is widely available in receivers manufactured for use by other navigation communities.

The FAA commissioned WAAS in July 2003. WAAS service supports departure, en route, arrival, and approach operations, including nonprecision approaches and approach procedures with vertical guidance. WAAS also supports additional capabilities such as advanced (curved and segmented) arrival and departure procedures, more efficient en route navigation and parallel runway operations, runway incursion warnings, high-speed turnoff guidance, and airport surface operations.

The WAAS will be incrementally expanded to increase the availability of service and improve signal redundancy. In preparation for L5 on modernized GPS satellites, the FAA will improve the WAAS to take advantage of this new signal. New dual-frequency avionics using WAAS and L5 will potentially provide a GNSS Landing System (GLS) precision approach capability (equivalent to ILS Category I operations).

3.1.3.3 The National Continuously Operating Reference Station (CORS) System

The National Geodetic Survey has established a national CORS system to support non-navigation post-processing applications of GPS. More recently, the CORS network has also served a troposphere and ionosphere monitoring network by those two scientific communities. Additionally, the national CORS is being modernized to serve as the foundation for future applications that support near- and real-time positioning (differing from navigation applications by the lack of a safety-of-life component). The national CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access by the Internet. As of March 2005, data were being provided from more than 650 stations.

The NGS manages and coordinates data contributions from GPS stations established by other groups rather than by building an independent network of reference stations. In particular, use is being made of data from stations operated by components of DOT and DHS that support real-time navigation requirements (mostly WAAS and NDGPS). These real-time stations make up approximately 26 percent of all national CORS stations. Other stations currently contributing data to the national CORS system include stations operated by the NOAA and NASA in support of crustal motion activities, stations operated by state and local governments in support of surveying applications, and stations operated by NOAA's Forecast Systems Laboratory in support of meteorological applications. The breakdown of CORS partners is illustrated in Figure 3-2.

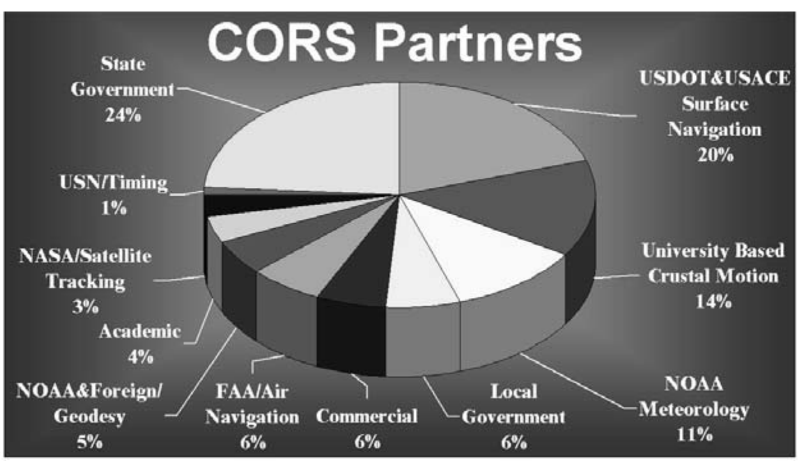


Figure 3-2. Partners in the Continuously Operating Reference Station System

3.1.3.4 *Global Differential GPS (GDGPS)*

The Global Differential GPS network consists of 70 dual-frequency GPS reference stations operational since 2000. Future NASA plans include developing the TDRSS Augmentation Service Satellites (TASS) to disseminate the GDGPS real-time differential correction message to Earth satellites and enable precise autonomous orbit determination, science processing, and the planning of operations in Earth orbit. The TASS signal will be transmitted on S-band from NASA's TDRSS satellites and also provide ranging signal synchronized with GPS.

The International GPS Service to which GDGPS contributes data, was formally recognized in 1993 by the International Association of Geodesy and began operations on January 1, 1994. It is recognized as an international scientific service, and it advocates an open data, and equal access, policy. NASA funds the IGS Central Bureau, which is located at JPL, and a global data center located at the Goddard Space Flight Center (GFSC). Over 10 years, IGS has expanded to a coordinated network of over 350 GPS monitoring stations from 200 contributing organizations in 80 countries. Other contributing U.S. agencies and organizations include, among others, the National Oceanic and Atmospheric Administration/National Geodetic Survey, the U.S. Naval Observatory, National Geospatial Intelligence Agency (NGA), and the National Science Foundation (NSF). Its mission is to provide the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education, as well as to facilitate other applications benefiting society. Approximately 100 IGS stations report with a latency of one hour. This data, and other information, may be obtained from the IGS website at: http://igscb.jpl.nasa.gov.

3.1.4 *Loran-C*

Loran-C is a stand-alone, hyperbolic radionavigation system that was originally developed to provide military users with a radionavigation capability with greater coverage and accuracy than its predecessor (Loran-A). It was subsequently selected as the radionavigation system for civil marine use in the U.S. coastal areas. It is approved by the FAA as a supplemental system in the NAS for the en route and terminal phases of flight and by the USCG as a means of maritime navigation in the coastal confluence zone. It is also available for use as either a primary or back-up precise frequency source to support precise timing applications. The Department of Defense has determined that Loran is no longer needed as a positioning, navigation, or timing aid for military users.

The Government continues to operate the Loran-C system in the short term while evaluating the long-term need for the system. This evaluation consists of two elements: a determination of the technical capability of a fully modernized and enhanced Loran system, and a cost-benefit analysis of developing and operating an enhanced Loran system.

The first part of the evaluation was completed in April 2004. The Office of the Secretary of Transportation, the FAA, and the USCG completed the technical evaluation of the ability of an enhanced Loran system to support nonprecision approach operations for aviation users and harbor entrance and approach operations for maritime users. As a result of and in conjunction with the technical evaluation, a number of decisions have been made:

- With respect to technical capability, the evaluation determined that an enhanced Loran system would be capable of providing nonprecision approach for aviation users and harbor entrance and approach for maritime users.

- With respect to aviation, the FAA has determined that sufficient alternative navigational aids exist in the event of a loss of GPS-based services, and therefore Loran is not needed as a back-up navigation aid for aviation users.

- With respect to maritime safety, the USCG has determined that sufficient back-ups are in place to support safe maritime navigation in the event of a loss of GPS-based services, and therefore Loran is not needed as a back-up navigational aid for maritime safety.

The second part of the overall evaluation is a cost-benefit analysis that is currently in progress. Specifically, two aspects remain to be evaluated:

- The Maritime Administration is evaluating whether the back-up systems or procedures currently employed in the Marine Transportation System are sufficient for maintaining maritime efficiency in the event of loss of GPS services. MARAD will update the USCG on progress throughout the study and solicit USCG input into the findings and recommendations. MARAD will then make a determination whether an enhanced Loran system is needed as a back-up navigation aid to maintain commercial maritime efficiency. This determination is expected to be completed by December 30, 2005.

- The Department of Homeland Security, in cooperation with DOT, is evaluating whether precise timing is a part of the U.S. critical infrastructure and whether a Federally provided back-up timing system is required. Concurrently, an analysis of alternatives, including the Loran system, will be conducted. This determination is expected to be completed by December 30, 2005.

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

3.1.5 VOR and DME

VOR was developed as a replacement for the Low-Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. A collocated DME provides the distance from the aircraft to the DME transmitter. At many sites, the DME function is provided by the TACAN system that also provides azimuth guidance to military users. Such combined facilities are called VORTAC stations. Some VOR stations also broadcast weather information.

The FAA operates approximately 60 VOR, 405 VOR/DME, and 590 VORTAC stations, plus another 30 DMEs collocated with NDBs. The FAA owns approximately 900 of these facilities; other Federal agencies, states, local governments, and private entities own the rest. Additionally, the DoD operates approximately 15 VOR, 18 VOR/DME, and 24 VORTAC stations, located predominately on military installations in the U.S. and overseas, which are available to all users. The current VOR/DME services will be maintained at their current level until 2010 to enable aviation users to equip their aircraft with GPS or GPS/WAAS avionics and to become familiar with the system. Plans for the maintenance of the network are limited to site modernization or facility relocation and the conversion of VORs having degraded signal propagation to a Doppler VOR configuration.

A reduction in the VOR population (only) is expected to begin in 2010. The proposed reduction will transition from today's VOR services to a minimum operational network (MON). The MON will support IFR operations at the busiest airports and serve as an independent civilian backup navigation source to GPS and GPS/WAAS in the NAS. Section 3.2 discusses the transition in more detail.

The FAA plans to sustain existing DME service to support en route navigation, and to install additional low-power DMEs to support Instrument Landing System precision approaches as recommended by the Commercial Aviation Safety Team. The FAA may also need to expand the DME network to provide a redundant RNAV capability for terminal area operations at major airports and to provide continuous coverage for RNAV operations at en route altitudes.

3.1.6 TACAN

TACAN is a tactical air navigation system for the military services ashore, afloat, and airborne. It is the military counterpart of civil VOR/DME. TACAN provides bearing and distance information through collocated azimuth and DME antennas. TACAN is primarily collocated with the civil VOR stations (VORTAC facilities) to enable military aircraft to operate in the NAS and to provide DME information to civil users.

The FAA and DoD currently operate approximately 114 "stand-alone" TACAN stations in support of military flight operations within the NAS. The DoD also operates approximately 30 fixed TACAN stations that are located on military installations overseas, and maintains 93 mobile TACANs and 2 mobile VORTACs for worldwide deployment. The FAA and DoD continue to review and update requirements in support of the planned transition from land-based to space-based primary navigation.

The DoD requirement for land-based TACAN will continue until military aircraft are properly equipped with GPS, GPS PPS receivers are certified for all operations in both national and international controlled airspace, and the GPS support infrastructure including published procedures, charting, etc., is in place. A phase down of TACAN systems is planned for a future date, yet to be determined. Sea-based TACAN will continue in use until a replacement system is successfully deployed. The Navy, Coast Guard and Military Sealift Command operate approximately 293 sea-based TACAN stations.

3.1.7 ILS

The Instrument Landing System is a precision approach system consisting of a localizer facility and a glide slope facility. It is frequently augmented by associated VHF marker beacons, DME, visibility sensors, approach lighting systems, and nondirectional beacons. An ILS provides vertical and lateral navigation (guidance) information during the approach and landing phase of flight and is associated with a specific airport runway end. Depending on its configuration and the other systems installed on the airport and in the aircraft, an ILS can support Category I, II, and III approaches.

ILS is the standard civil precision approach system in the U.S. and abroad. The FAA operates 1,275 ILS systems in the NAS of which 225 are localizer only and 115 of which are Category II or Category III systems. In addition, the DoD operates 160 ILS facilities in the U.S.

As the GPS-based augmentation systems (WAAS and Local Area Augmentation System (LAAS)) are integrated into the NAS, and user equipage and acceptance grows, the number of Category I ILSs will be reduced. The proposed reduction will transition from today's full-coverage network to a minimum operational network that will support IFR operations at the busiest airports in the NAS. Section 3.2 discusses the transition in more detail. LAAS is discussed in Section 4.2.1.

The FAA does not anticipate phasing out any Category II or III ILS systems until LAAS is able to deliver equivalent service and GPS vulnerability concerns are addressed. A reduction in the number of Category II/III ILSs may then be considered. Until LAAS systems are available, new and upgrade Category II and III precision approach requirements will continue to be met with ILS.

3.1.8 MLS

The FAA does not anticipate additional civil Microwave Landing System development. The phase-down of MLS is expected to begin in 2010.

3.1.9 Aeronautical Nondirectional Beacons (NDB)

NDBs serve as nonprecision approach aids at some airports; as compass locators, generally collocated with the outer marker of an ILS to assist pilots in getting on the ILS course in a non-radar environment; and as en route navigation aids.

The NAS includes more than 1,300 NDBs. About 225 are owned by the FAA and 50 by the DoD; the rest are non-Federal facilities owned predominately by state and municipal authorities. FAA expenditures for beacons are planned to be limited to the replacement of deteriorated components, modernization of selected facilities, and an occasional establishment or relocation of an NDB used for ILS transition.

The FAA has begun decommissioning stand-alone NDBs as users equip with GPS. NDBs used as compass locators, or as other required fixes for ILS approaches (e.g., initial approach fix, missed approach holding), where no equivalent ground-based means are available, may need to be maintained until the underlying ILS is phased out. Most NDBs that define low-frequency airways in Alaska or serve international gateways and certain offshore areas like the Gulf of Mexico will be retained.

3.1.10 Marker Beacons

Marker beacons transmit 400 Hz, 1300 Hz, or 3000 Hz tones on a frequency of 75 MHz. Markers, as they are called, provide audible and visual identification of positions along the final approach path of a precision instrument approach. There are also some marker beacon transmitters for en route navigation, which are referred to as fan markers. The FAA intends to phase down marker beacons in favor of using published distances to a DME facility or establishing navigation waypoints collocated with the existing marker beacon facilities that will enable aircraft to determine progress along the approach to runway.

3.2 Aeronautical Navigation and Landing Transition Strategy

3.2.1 Civil Air Transition to Satellite-Based Navigation (Satnav)

The FAA is planning to transition into providing Satnav services based primarily on GPS augmented by the WAAS, with Category II and III service based on the LAAS and ILS. As a result of this transition, the need for ground-based navigation services will diminish and the number of Federally provided ground-based facilities will be reduced accordingly. The proposed transition strategy is depicted in Figure 3-3. The FAA is evaluating alternatives for the future NAS navigation architecture and will update the transition plans as Satnav program milestones are achieved, as the actual performance of Satnav systems is documented, and as users equip with Satnav avionics.

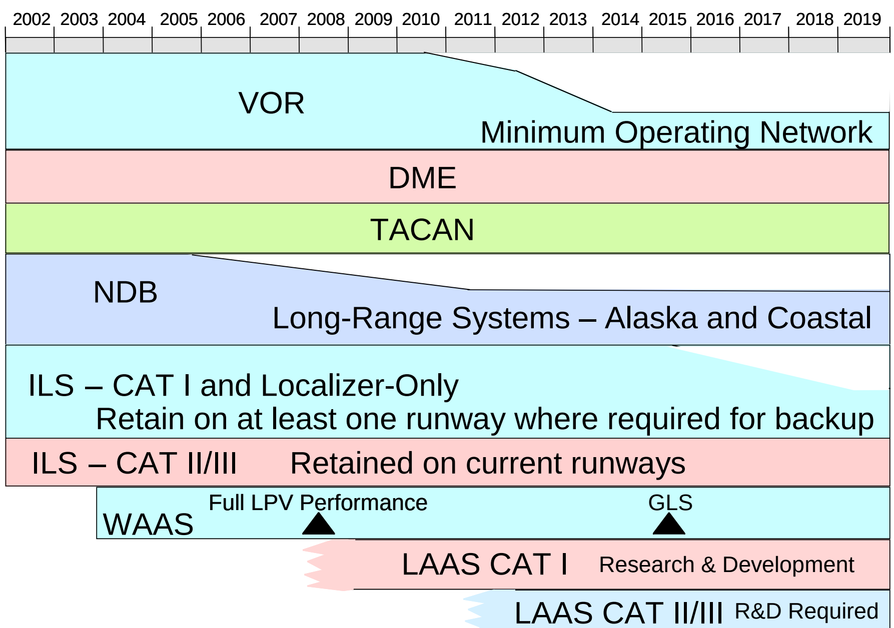


Figure 3-3. Proposed Civil Aeronautical Navigation and Landing Transition

The FAA will conduct the planned reductions gradually, providing users sufficient time to equip with Satnav avionics. The reductions are planned to begin in 2010 based on projected satellite navigation program milestones, including the publication of procedures, and anticipated user equipage rates.

The specific Navaids to be discontinued at each step of the transition will be determined based on specific criteria, currently under development. The discontinuance criteria, and a site-specific list of Navaids, will be published well ahead of the reductions. The advanced site-specific notice will afford users the opportunity to plan their transition to Satnav based upon the operational schedule for the specific Navaids they use most often. The necessary amendments to those flight procedures that will remain after this transition will be planned and completed before specific Navaids are discontinued.

- *Interim Network* – Many currently underutilized VORs and ILSs will be discontinued in the early stages of the transition. Preliminary analysis indicates that approximately 350 VORs and 300 ILSs could be discontinued, representing a reduction to approximately 70 percent of the current Navaid population.
- *Minimum Operational Network* – When the transition is completed, the population of ground-based Navaids will have been reduced to the level of a proposed Minimum Operational Network that provides an independent back-up radionavigation source. The MON will support continued operation in the NAS by those aircraft not equipped with Satnav avionics at a reduced level of airspace access or efficiency (e.g., more circuitous routes between some airports). The MON will also provide the FAA and the airspace users with a safe recovery and sustained operations capability in the event of a disruption in Satnav service. The MON represents a reduction to approximately 50 percent of today's VOR and Category I ILS population.

3.2.2 Airport Implementation Issues

GPS represents a fundamental departure from traditional point-to-point, ground-based navigation systems technology with respect to aviation approach operations. Ground-based systems provide services that are somewhat limited to the location where they are installed. A ground-based system (such as an ILS) only provides services to a single runway. In theory, GPS approach operations can be made available to any existing runway in the NAS with or without ground-based radionavigation equipment. However, obstruction removal and other airport improvements are often needed to provide the full benefit of GPS approach operations.

3.2.3 Long-Term Transition Plans

The pace and extent of the transition to Satnav will depend upon a number of factors related to system performance and user acceptance. The FAA plans to reduce ground-based Navaids subject to these factors. The specific level of retention of ground-based Navaids to support satellite navigation does not need to be determined until well after experience is gained with Satnav technology. Some site-specific Navaids will reach the end of their serviceable life before 2010. The need to replace selected Navaids will require investment analysis and investment decisions on what specific Navaids to retain.

The FAA's plans for the transition to Satnav and for the reduction of ground-based Navaids will be periodically reevaluated. These plans need to remain flexible, and may need to be adjusted as satellite navigation program milestones are achieved, as the actual performance of Satnav systems is demonstrated, and as users equip with Satnav avionics. The transition plans will continue to be coordinated with airspace users and with the FAA's air traffic control community.

3.3 Mitigating Disruptions to Satellite Navigation Services

The Department of Transportation, in conjunction with other governmental agencies, is developing and implementing mitigation plans in response to the recommendations of the Volpe National Transportation Systems Center report: *Vulnerability Assessment of the Transportation Infrastructure Relying on Global Positioning System (Ref. 7)*, as well as other U.S. Government critical infrastructure protection initiatives. In addition, the U.S. Space-Based Positioning, Navigation, and Timing Policy directs the Department of Transportation, in coordination with the Department of Homeland Security, to develop, acquire, operate, and maintain back-up positioning, navigation, and timing capabilities for critical civil and commercial applications within the U.S., in the event of a disruption to GPS or GPS augmentations.

3.3.1 Mitigating Disruptions in Aviation Operations

The FAA will continue to operate and maintain a network of ground-based Navaids for the foreseeable future. However, the FAA is committed to delivering satellite-based navigation service capable of supporting operations throughout the NAS without routine reliance on other navigation systems. Even when this goal is attained, many operators are expected to choose to retain other radionavigation receivers, and it is possible that inertial navigation systems could be required for some operators. Procedural means will also be used to maintain safe operations in the event of a loss of GPS. A number of studies and evaluations are underway to help determine the feasibility of this goal. The FAA will update the navigation strategy if necessary to ensure safe and reliable air transportation. Critical issues to be addressed are discussed below.

Ionospheric scintillation during severe solar storms is also a concern, but is expected to have only minimal impact on en route, terminal and nonprecision approach operations. However, ionospheric anomalies cause periodic outages of localizer performance with vertical guidance (LPV) approach capability using WAAS.

A loss of GPS service, due to either intentional or unintentional interference, in the absence of any other means of navigation, would have varying negative effects on air traffic operations. These effects could range from nuisance events requiring standard restoration of capabilities, to an inability to provide normal air traffic control service within one or more sectors of airspace[*] for a significant period of time.

[*] The NAS is divided into hundreds of air traffic control "sectors." A single air traffic controller has the responsibility to keep aircraft safely separated from one another within each sector. Sector dimensions vary, and are established based on predominant traffic flows, altitude, and controller workload.

In addition to FAA plans of retaining a minimum network of VOR, DME, and ILS facilities to serve as a backup to GPS, several other solutions have been identified to help mitigate the effects of a Satnav service disruption, but each has its limitations.

- The L5 civil frequency planned for GPS will help mitigate the impacts of both solar activity and unintentional interference, but it may be 2015 before a full constellation of dual-frequency satellites (L1 and L5) is available. When implemented in WAAS, this signal will preserve LPV capability during severe ionospheric activity.

- Modern transport-category turbojet aircraft with inertial systems, when engaged in relatively stable en route flight, may be able to continue navigating safely for a period of time after losing radionavigation position updating depending on the route or procedure being flown. In some cases, this capability may prove adequate to depart an area with localized jamming or proceed under visual flight rules during good visibility and high ceilings. However, inertial performance without radionavigation updates degrades with time and will eventually fail to meet airspace requirements.

- Integrated GPS/inertial avionics having significant anti-jam capability could greatly reduce the area affected by a GPS jammer or by unintentional interference. Industry research is proceeding to develop this technology, with an expectation that it might be marketed to the general aviation community. However, significant technical challenges remain to be resolved to ensure that this technology works correctly, and some users may still find this technology to be unaffordable.

- Users may have an option to equip with instrument flight rules (IFR)-certified Loran-C avionics, pending the improvements needed to achieve a nonprecision instrument approach capability with Loran. A combined Loran/Satnav receiver could provide navigation and nonprecision instrument approach service throughout any disruption to Satnav service.

- If a majority of operations are conducted by aircraft equipped with an additional navigation capability (e.g., inertial, DME, VOR or Loran), then the balance should be able to be managed with air traffic control vectors based on an independent (e.g., radar) surveillance system. Additional research may be necessary to validate this concept in terms of the impact to air traffic controller workload and the sensitivity to the proportion of backup-equipped aircraft.

3.3.2 Mitigating Disruptions in Maritime Operations

The USCG has identified two critical maritime applications:

- Inland waterway and harbor entrance and approach.

- Timing and synchronization (maritime Automatic Identification System (AIS) standard).

Mariners practice “conventional” navigation, using “all available means” which includes GPS/DGPS, Loran-C, radar, lights/buoys/daymarks, celestial navigation, fathometer, paper charts and dead reckoning. In addition, the USCG controls waterway activity, under the authority vested in the Captain of the Port by closing waterways or restricting marine activity during adverse weather conditions or special operations. These combined elements facilitate safe waterway navigation.

Rather than being identified as a weakness, universal AIS is an example of how a new technology can be designed around GPS while at the same time implementing measures that mitigate the impact of the potential vulnerabilities of GPS. Specifically, the universal AIS design team has been aware of the potential GPS failure mechanisms. Although Universal AIS uses GPS for primary timing, secondary timing is provided by an external synchronization method that is based upon the reception of other AIS stations' broadcasts. Loss of GPS timing will not prevent AIS from operating, although the capability to apply accurate "time tags" to the data packets would be lost.

In the case of AIS, the architecture is structured to gracefully degrade with loss of the primary position sensing system (like GPS). To accomplish this, it makes use of a hierarchy of eight levels of position sensing systems with GPS/DGPS at the high end and dead reckoning at the low end. For example, at the fourth stage of operation, the electronic position source can be any external electronic position fixing system, such as Loran-C. These eight stages provide for significant AIS survivability in the face of a variety of navigation threats. The completeness of the navigation information will depend upon the number and type of secondary navigation information sources actually employed by the AIS aboard the vessel.

The USCG is working closely with other maritime nation members to address disruptions through updated performance standards for GPS receivers to reduce vulnerability to interference. The USCG continues to work with other committees that are improving equipment standards or determining alternative solutions to better deal with these issues.

3.3.3 Mitigating Disruptions in Land Operations

Land transportation users currently use radionavigation services from GPS and its augmentations to supplement other available non-radionavigation systems. Under this operational paradigm, users seamlessly use other existing techniques to mitigate both the short-term loss of GPS due to obstructions and the longer-term loss due to failed on-board user equipment and adverse operating environments. In future applications, accuracy requirements are expected to become much more stringent, and GPS and its augmentations are likely to play a more critical role. The loss of GPS and its augmentations will be carefully evaluated within the overall operational environment to ensure continued safe and efficient operation of the surface transportation system.

Land transportation agencies are working with industry to ensure that safety critical systems that use GPS and its augmentations consider the loss of these radionavigation services and are able to mitigate its effects in order to continue safe and efficient operation of the nation's surface transportation infrastructure. This is accomplished today by outreach to user groups and local transportation agencies and defining minimum operational or functional standards. In the future, training for application developers, state and local highway and transit agencies, and motor carriers on the operational capabilities of GPS as well as what to do when failures occur may be necessary. Finally, since it is expected that signal availability from GPS may not be adequate for surface users experiencing canopy/urban obstructions, alternate systems that perform a verification test on the GPS navigation solution and that support continued operation in the event of a loss of GPS will be employed in a system-of-systems configuration.

3.3.3.1 Mitigating Disruptions in Railroad Operations

The Federal Railroad Administration's Intelligent Railroad Systems initiative encourages an integrated approach to technology that incorporates systems that are interoperable, synergistic and redundant. For example, since GPS is susceptible to jamming and unintentional interference, FRA encourages the use of technologies and procedures that cannot be jammed or interfered with as a backup. These technologies and procedures include inertial navigation systems, sensor circuits, signaling systems, and dispatcher operations. These redundant systems and procedures ensure the safe and efficient operation of the railroad system during the loss or disruption of GPS. Similarly, since all radionavigation systems are susceptible to interference, radionavigation systems are not considered acceptable backups to GPS for rail applications.

Recognizing that satellite navigation services can be disrupted, FRA will:

- Work towards bringing anti-jam capable receivers to the railroad industry.
- Encourage the incorporation of low cost Inertial Navigation Units (INU) in Positive Train Control (PTC) systems.
- Develop the capability to update INUs automatically via inputs from railroad sensors, and manually when a locomotive passes a milepost.
- Develop equipment standards and architectures for use in railroad applications.
- Advocate robust signal structures for satellite navigation services and their augmentation systems such as NDGPS.
- Work with other agencies and the international community to prevent and mitigate disruptions of satellite navigation services and their augmentation systems such as NDGPS.

3.3.4 Mitigating Disruptions in Non-Navigation Applications

Common positioning applications include surveying and mapping. These applications have a highly variable duration and involve sporadic areas of operation. Because of the flexible character of positioning applications, operations will typically be halted until the GPS signal is restored in an area. Optical and inertial surveying equipment are back-up options that could meet the accuracy requirements of these applications, depending on the capabilities and preparation of these operators.

3.3.5 *Mitigating Disruptions in NASA Applications*

Dual-frequency GPS receivers have been certified for Space Shuttle navigation, and were chosen for being less susceptible to disruption. As of December 2004, the status of the Shuttle fleet is:

- OV-103 (Discovery) and OV-104 (Atlantis) have one PPS GPS receiver and three TACAN units. A method of simultaneously using GPS and TACAN has been developed, and will be used soon after the Shuttle return-to-flight (note: STS-114/Discovery will not use GPS except during an emergency). Should GPS service be disrupted, TACAN is available for navigation. Current plans call for a Shuttle end-of-fight in 2010, well before TACAN phase-down.

- OV-105 (Endeavour) has had its TACAN units removed and, instead, will use three PPS GPS receivers as the primary navaids for re-entry.

The Inertial Navigation System (INS), which is the primary navigation system, is updated through position fixes from GPS (single string) and TACAN in OV-103 and OV-104, and a three string GPS on OV-105. Therefore, brief disruptions in GPS would initially be compensated by the INS. Should GPS service be disrupted prior to entry, emergency procedures call for tracking using ground-based C-Band radar. Additional redundancy is provided through drag and barometric altimeters, as well as Microwave Landing Systems at the landing sites in Kennedy Space Center, Edwards, White Sands, as well as the emergency launch-abort landing sites in France and Spain. During entry operations, the landing sites may be monitored for interference to GPS. During re-entry, the landing site at Kennedy Space Center is continuously monitored for GPS interference.

A number of GPS receivers have been tested on spacecraft for real-time navigation and attitude determination. GPS facilitates autonomous operations in Earth orbit and reduces operational costs and communications bandwidth. Should GPS service be disrupted, then ground-based tracking could be used for navigation and on-board backup instruments such as magnetometers, Earth sensors, and directional antennas for attitude determination. Mitigations range from the use of lower accuracy navigation methods (e.g., laser corner reflectors on the Jason ocean surface topography mission) to no mitigation. For example, the GRACE gravity field measurements and COSMIC ionospheric sensing and space weather satellite constellations which would lose the primary science data during GPS signal interruptions.

3.3.6 *DoD GPS Security Program*

In the December 2004 U.S. Space-Based Positioning, Navigation, and Timing Policy, the President directed that the Secretary of Defense shall develop, acquire, operate, realistically test, evaluate, and maintain navigation warfare capabilities.

The DoD Navigation Warfare (Navwar) program exists to ensure that the United States retains a military advantage in an area of conflict by: protecting authorized use of GPS; preventing the hostile use of GPS and its augmentations; and preserving civilian uses outside an area of conflict.

This research and development (R&D) effort will require periodic testing which may impact the civil use of GPS. DoD and DOT have developed mechanisms to coordinate times and places for testing, and will notify users in advance.

3.4 DoD Certification of PPS Receivers

DoD is in the process of self-certifying PPS receivers for use in the NAS and international airspace. This self-certification is being done equivalent to civil standards. DoD will also work with the military establishments of its international allies to seek approval for use of PPS receivers in foreign airspace. The Department of Defense does not have an operational requirement to use the civil L5 signals or WAAS. Since DoD policy prohibits the use of civil signals or augmentation systems in wartime environments and dual equipage is not fiscally practicable, self-certification of PPS receivers is required to eliminate the need for civil GPS equipage on military aircraft. Commercial operators of Civil Reserve Air Fleet (CRAF) airframes could elect to equip with L5 and/or WAAS if there is a demonstrated benefit at the civil airports where these aircraft are operated. Self-certification will provide enhanced capability to span the operational environment for military aviation—from flight in civil airspace in peacetime to combat operations worldwide.

4

Research and Development Summary

4.1 Overview

This section describes Federal Government radionavigation system research and development (R&D) activities. It is organized in two segments: (1) civil R&D efforts to be conducted by DOT and other Government organizations for civil purposes, and (2) DoD R&D.

Civil R&D activities emphasize the enhancement of GPS for civil applications. Civil R&D activities may involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies, and determination of future requirements for the certification of equipment. DoD R&D activities mainly address enhancements necessitated by national security considerations, extended military mission requirements, and new civil requirements (e.g., the new second and third civil signals). Where appropriate, civil agencies and the DoD exchange operational and technical information on radionavigation systems R&D development programs.

4.2 Civil R&D

Civil R&D activities are being conducted primarily by the FAA, the USCG, the FHWA, and the ITS/JPO. A majority of these efforts are focused on determining methods to satisfy ever increasing civil user requirements for satellite navigation services in the air, marine, and land transportation communities. Civil augmentations to GPS have been developed to meet many such requirements, and R&D activities continue to focus on a number of specialized systems optimized to meet increasing civil user requirements.

In addition, the Research and Innovative Technology Administration is conducting a series of research activities in transportation infrastructure assurance, including reviews of system interdependencies and the vulnerability of systems related to electronic commerce. Navigation and radionavigation systems are being included in the scope of these projects.

4.2.1 Aviation

The FAA is conducting R&D in the LAAS program in conjunction with the introduction of satellite navigation into the NAS. Research is also ongoing to support the procurement of replacement DME, and to support a decision by the Department of Transportation whether to continue operating the Loran-C system. The agency is also initiating a program to pursue interference detection, location, and mitigation.

4.2.1.1 LAAS R&D Activities

LAAS is a ground-based GPS augmentation system being developed by the FAA. LAAS is expected to provide the required accuracy, availability, integrity, coverage, and continuity to initially support Category I precision approaches and eventually Category II and III precision approaches.

LAAS will augment GPS by providing differential corrections to users via a VHF data broadcast. LAAS will allow suitably equipped aircraft to conduct precision approaches in the vicinity of LAAS-equipped airfields. LAAS will also allow suitably equipped aircraft to conduct curved approaches, segmented approaches, and other RNAV approaches within the terminal area.

The following items illustrate the research currently underway to support the Category I and Category II/III LAAS capabilities:

Category I

- Quantify and characterize the rapid changes in ionospheric range delay, and evaluate methods of mitigation.
- Continue research into ground reference receiver multipath modeling to enhance system availability.
- Complete an integrity threat characterization and analysis of monitoring algorithms necessary to demonstrate that LAAS can be certified for Category I service.

Category II/III

- Evaluate effects of intentional and unintentional RFI on the performance of the system, and evaluate methods of mitigation.
- Develop methods to perform ground system integrity monitoring.

- Perform analysis to confirm that proposed alert limits and time-to-alert can be met with the LAAS architecture.

- Evaluate system performance parameters and requirements to support surface navigation and surveillance applications.

- Investigate the integration of GNSS with technologies such as inertial measurement systems, enhanced vision systems, and radar altimeters that will enable aircraft to achieve Category II/III capability. This effort is expected to lower the performance requirements for the Category II/III (LAAS ground facility) LGF.

4.2.1.2 DME R&D Activities

The FAA is studying the effects of the over-interrogation of currently operated DME ground transponders. When too many interrogations are received from airborne DME equipment, DME ground transponders become “saturated.” They typically respond by rejecting weaker interrogations from more distant aircraft or from closer aircraft with lower-powered DME interrogators. As a result, service can be denied to aircraft that are within the expected coverage area of the DME. Aspects of the program include:

- Evaluating the response of different generations of DME ground transponders to the effects of over-interrogation.

- Developing improved performance specifications and design standards for a next generation of DME ground transponders and airborne DME equipment.

4.2.1.3 Interference Detection, Location, and Mitigation

Concurrent with the development of communication, navigation, and surveillance systems, the FAA will be developing enhanced interference detection and locating capabilities to help mitigate the impacts of RFI on present and future NAS systems. New capabilities such as GPS, Next Generation Air/Ground Communications (NEXCOM), aeronautical data link systems, and Automatic Dependence Surveillance-Broadcast (ADS-B) will require enhanced radio frequency and electromagnetic interference detection capabilities. Program requirements include:

- Developing the ability to detect, locate, and mitigate the impact of both intentional and unintentional interference on NAS elements and capacity.

- Scoping a robust but affordable program that will prevent a loss in the projected system gains achieved by the new NAS systems, and assure that the end users benefit from the significant investments being made.

4.2.2 Maritime

The USCG is exploring accuracy enhancement and the integration of NDGPS with other navigation sensors. Particular emphasis is being placed upon the integration of NDGPS with inertial navigation systems. Efforts are being conducted to determine the ability of

INS to enhance GPS/DGPS navigation service, and to provide heading information for Electronic Chart Display and Information System (ECDIS) use. Work is being conducted with RTCM Special Committee 104 (SC104) in developing new high accuracy messages, including ones optimized for use with Selective Availability (SA) set to zero. This work includes the development of corrections for ranging signals broadcast from geo-stationary satellites. Also, several promising improvements to the NDGPS data link are being studied that have the potential to further mitigate the effects of impulse noise and interference.

Increasing numbers of WAAS receivers have emerged in the public marketplace and are being used in the maritime regions. As a result, comprehensive testing and evaluation of WAAS accuracy, availability, and integrity required in maritime applications is being conducted to determine if WAAS satisfies the performance requirements for maritime navigation and positioning applications (e.g., buoy positioning, HEA navigation, and inland waters navigation). The testing and evaluation involves a combination of shore and vessel data collection, as well as WAAS modeling.

The Coast Guard is developing a set of analysis tools to allow performance evaluations of navigation systems in specific ports and waterways. These tools will help assess the relative level of safety expected from radio aids, navigation equipment, and short range aids to navigation intended to be used for HEA navigation.

4.2.3 Land

GPS and its augmentations offer navigation services that far exceed what was envisioned only a few short years ago. With the tremendous success of GPS and its current augmentations, new applications requiring even more precise accuracy, integrity, and availability are being discovered. FHWA, USCG, NOAA, and other Federal agencies, as well as State and local governments, agencies, academia, and industry are working together to develop more precise and robust augmentations for GPS, creating terrestrial navigation systems that will significantly improve the safety and economic well being of the nation. The goal is to achieve 10 cm real time navigation, a three to five second integrity function, and an availability of greater than 99 percent. For non-safety-of-life applications, the accuracy goals may be as stringent as 1 cm or better in real time.

4.2.3.1 High Accuracy NDGPS

The High Accuracy NDGPS (HA-NDGPS) system is currently under development in order to enhance the performance of NDGPS. The first HA-NDGPS station began broadcasting in a test mode in 2001 with funding from the Interagency GPS Executive Board (IGEB). The IGEB recognized the potential benefit to many Federal agencies, states, and the general public of having a nationwide high accuracy system. Two HA-NDGPS reference stations are currently operational and providing 10 to 15 cm accuracy throughout the coverage area. Further improvements to accuracy and the development of 1 to 2 second time-to-alarm integrity are anticipated. Once these improvements are complete, a HA-NDGPS standard will be developed.

To support this, several approaches are being investigated. They can be grouped into three general categories: improved ionosphere and troposphere prediction; increased data throughput to support broadcast of GPS observables; and the addition of pertinent data to the current broadcast. Each is discussed in the following sections.

Improved Ionosphere and Troposphere Prediction

Large errors and rapid changes in GPS positional accuracy can occur during significant space and tropospheric weather events, and no currently available signal delay models can provide high accuracy corrections under these conditions. FHWA, in collaboration with the USCG and NOAA, is evaluating the feasibility of using weather models to calculate GPS signal delays caused by the ionosphere and troposphere, create differential correction messages for broadcast, and use them to help resolve carrier phase ambiguities over arbitrarily long baselines.

Increased Data Throughput for Broadcast of GPS Observables

A second line of research is determining the feasibility of broadcasting navigation satellite observables. The focus of this effort has been the development of a low cost modification to existing NDGPS facilities in order to maximize the benefits of these facilities. The NDGPS site near Hagerstown, MD, was modified in April 2002 and a second site, Hawk Run, PA, was modified in July 2003. The effort has been divided into two phases.

Phase I was a proof of concept and implementation phase that determined the viability of modifying an NDGPS facility and examined the accuracy available from a single site. A broadcast data rate of 1000 bps was established as the maximum allowable. A second transmitter, transmission line, and diplexer were added to the Hagerstown NDGPS facility.

Testing began shortly after installation. Testing using this single site achieved a horizontal navigation solution of within 10 cm (95 percent) of truth at a range of approximately 250 km. This testing is documented in the Phase I final report available at: http://www.tfhrc.gov/its/ndgps/02110/index.htm.

Addition of Pertinent Data

With SA set to zero, differential GPS (DGPS) latency requirements for pseudorange correction data can be eased and range rate data may no longer be needed by users. Service providers are aggressively pursuing methods to leverage newly available data link capacity to enhance system performance. Methods being explored include:

- Improved "post SA" reference station correction generation algorithms that increase accuracy.
- Improved integrity monitoring processes that reduce user vulnerabilities.
- Differential corrections that enable use of WAAS pseudo-ranges in DGPS position solutions.
- Enhanced beacon almanacs that enable users to intelligently select the best beacon by signal specification.

- Highly accurate atmospheric corrections generated by NOAA using wet/dry tropospheric and ionospheric data.
- Network distribution of correction data between adjacent beacon sites.
- Distribution of precise orbit data over the DGPS data link.

4.2.3.2 Application Development

The land transportation modes have been working for many years to establish supportable values for navigation. In recent years, this effort has been focused on two primary land transportation modes – rail and highway. In each mode, the lead Federal organization has been working with private sector organizations to cooperatively analyze and develop prototype systems to further evaluate the viability and effectiveness of the prototype, ensuring that there is no loss in transportation safety.

4.2.4 Rail

The FRA in conjunction with other agencies and the railroad industry is working on the development of Intelligent Railroad Systems that use sensors, computers, and digital communications to collect, process, and disseminate information to improve the safety, security, and operational effectiveness of railroads. Integral to many Intelligent Railroad Systems is the requirement for the accurate, real-time, position of locomotives, rail cars, maintenance-of-way vehicles, tracks, and wayside equipment through the use of radionavigation and positioning services.

FRA's Office of Research and Development is working with other Federal agencies, states, universities, and industry to develop radionavigation and positioning services to meet two FRA requirements. The first requirement is for a system that provides 1 meter accuracy (95 percent), 6 second time to alarm integrity when the system is out of tolerance and ubiquitous coverage over all U.S. railroads. When combined with other sensors such as track circuits and INU, the combined system must be available 99.999 percent of the time and determine which track the train is on and whether or not the train has cleared a switch with a degree of confidence 0.99999. These requirements are needed for Positive Train Control and general train operations.

PTC is an integrated command, control, communications, and information system for controlling train movements with safety, security, precision, and efficiency. PTC will improve railroad safety by significantly reducing the probability of collisions between trains, casualties to roadway workers and damage to their equipment, and over speed accidents. The National Transportation Safety Board (NTSB) has named PTC as one of its "most-wanted" initiatives for national transportation safety. PTC systems are comprised of digital data link communications networks, continuous and accurate positioning through the use of HA-NDGPS, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems issue movement authorities to train and maintenance-of-way crews, track the location of the trains and maintenance-of-way vehicles, have the ability to automatically enforce movement authorities, and continually update operating data systems with information on the location of trains, locomotives, cars, and crews. The remote intervention capability of PTC permits the control center to stop a train should the locomotive crew be incapacitated. In addition to providing a greater level of safety and security, PTC systems also enable a railroad to run scheduled operations and provide improved running time, greater running time reliability, higher asset utilization, and greater track capacity. FRA selected NDGPS to meet the positioning requirements for PTC and is working with other Federal agencies, states, universities, and industry to improve the accuracy of service and to expand it to provide dual coverage nationwide.

The second FRA requirement is for a real-time, nationwide service that provides 10 cm horizontal accuracy and 15 cm vertical accuracy for rail surveying, rail defect detection, and scientific applications involving railroad test cars. FRA is working with other Federal agencies, universities, and industries in the development of the HA-NDGPS to meet these requirements. The first prototype HA-NDGPS site was installed at the Hagerstown, Maryland NDGPS site. Both the high accuracy and original NDGPS are broadcast from the reference station, so the users have backward compatibility to the original NDGPS signal and can take advantage of the new high accuracy signal if needed. This prototype site proved that 10 cm accuracy at distances of up to 250 km from the reference station can be achieved. Agencies will continue to work to: improve the accuracy; improve the range from the reference station that the high accuracy can be achieved; decrease the time it takes to converge on the high accuracy solution; and ensure that the system is robust enough for the railroad environment. After this prototype work is completed, a standard will be developed, and the system will be implemented nationwide.

4.2.5 Highway and Transit

Highway applications today are focused on assisting travelers in routing or in fleet management. Near term research is underway to examine the ability to provide warnings to drivers of potential critical situations, such as stop sign violation or crashes. Longer-term research is examining the potential for minimal vehicle control when there is a clear need for action. This could take the form of pre-deployment of air bags to braking.

The Intelligent Vehicle Initiative (IVI) is examining the long-term needs of the transportation system. The IVI research currently underway is in the area of advanced driver assistance systems, which include road departure and lane change collision avoidance systems. These systems need to estimate the lateral position of the host vehicle relative to lane and road edge with an accuracy of 10 cm. The IVI program is engaged in a research program to determine if the position accuracy of the vehicle can be determined with radionavigation techniques coupled with inertial sensors.

Most transit agencies now procure Automatic Vehicle Location systems that use GPS. In the 1990s, radionavigation methods such as Loran-C and GPS both looked promising, and as costs declined, the technologies became more attractive. In the early 1990s, a few transit agencies deployed Loran-C aided with dead-reckoning sensors. Loran-C was not accurate enough and was soon abandoned. As GPS became operational and GPS receivers were miniaturized and decreased in price, it became the sensor of choice. Today, most new systems use DGPS technology. Additional research into driver assistance systems and other applications continues. Some promising technologies include automated docking and arrival annunciation.

4.2.6 NASA

NASA is conducting R&D in a number of GPS application areas in the space, aeronautics, and terrestrial environments. These efforts include:

Space Applications: The emphasis in the space applications R&D of GPS is primarily in three areas:

- Satellite Navigation: Use of GPS receivers onboard satellites to provide spacecraft positioning and navigation data. Research in this area primarily involves development of new software programmable receivers and the autonomous navigation software that can be used for autonomous operation of science satellites. This includes development of techniques for use of GPS for autonomous satellite positioning above the GPS constellation out to Geo-synchronous Earth Orbit (GEO) and above.

- Satellite Precise Positioning: Use of GPS receivers on research satellites for precise positioning in support of onboard science instruments. The goal of this research is to provide precise satellite positioning at the 10 cm level in real time. The ability to perform at this level will enable numerous scientific measurements not available today to support research in areas such as oceanography and mapping. In order to demonstrate the ability to achieve this level of precision, NASA is currently developing the TDRSS Augmentation Service Satellites (TASS) to disseminate the GDGPS real-time differential correction message to Earth satellites, and enable precise autonomous orbit determination, science processing, and planning operations in Earth orbit. The TASS signal will be transmitted on S-band from NASA's TDRSS satellite, and will also provide a ranging signal synchronized with GPS.

- GPS as a Science Instrument: Use of GPS signals for science observations will be the subject of continuing research. Examples of this research are the use of GPS signals for atmospheric research using occultation measurements through the Earth's atmosphere, and observations of GPS signals reflected off of the Earth's surface.

The latest generation of NASA GPS spaceborne receivers will be software programmable units that will include the capability to receive the second civil signal. NASA has already started to work on adding the second civil frequency capability to this receiver and plans to begin flight tests on the capability as GPS satellites with the second civil signal become available.

Aeronautics Applications: NASA will continue to use GPS receivers aboard NASA aircraft for both aeronautics research and in support of airborne scientific observations. There are numerous projects throughout NASA where GPS technology is being developed for these purposes. Airborne GPS receivers have been used to support NASA scientific research in areas such as Airborne Synthetic Aperture Radar (AIRSAR) and in Greenland ice sheet thickness measurements.

NASA is also experimenting with using GPS in a "windowless cockpit" application where GPS positioning is used together with a detailed three-dimensional map of the Earth to provide synthetic vision for the crew in control of future high-speed vehicles.

This same technique may also be used in commercial aviation as an important safety aid to avoid controlled flight into terrain accidents.

Terrestrial Applications: NASA is supporting the continued development of the IGS. The data received from this network of GPS monitoring stations are providing data products on a daily basis that are distributed via the Internet for users worldwide. One of the direct products of the IGS is measurement of Earth crustal movement at the centimeter per year level. In addition, a possible byproduct of this research could be the eventual development of reliable techniques to be used for earthquake early warning and prediction.

NASA has developed a high accuracy GPS augmentation system to support the demanding real-time positioning, timing, and orbit determination requirements of its science mission. GDGPS enables 10-20 cm real-time positioning accuracy for users with dual-frequency GPS receivers. Very high end-to-end reliability is enabled through a redundant architecture. Data from the GDGPS tracking network is made available to the public on an hourly basis through the data archiving services of NASA.

Launch Range Architecture: Space-based navigation, GPS, and space-based range (SBR) safety technologies are key components of the next generation launch and test range architecture being developed by NASA with assistance from DoD and the FAA. A space-based range would provide a more cost-effective launch and range safety infrastructure while augmenting range flexibility, safety, and operability to better accommodate more diverse and dispersed (multiple launch ranges) space operations in the future. Development projects are underway using GPS-based tracking as a primary means of launch vehicle tracking and surveillance.

Also in the future, reusable launch vehicles (RLV) are expected to be included in the mix of aviation and space traffic. Full access to space from any of the spaceports that RLVs might use requires compatible launch and telemetry tracking and control (TT&C) systems, which are not locked into one or two geographic locations with fixed radars. This implies the development of a cost-effective space-based range and TT&C infrastructure, with global coverage. The future Space and Air Traffic Management System (SATMS) network under development for aviation and space provides a long-term answer for the full spectrum of coverage and control that is needed. A working concept of operations for SATMS has been developed.

Other research and development work is also underway for future generations of vehicles to transition to GPS-based guidance, navigation, and autonomous flight termination systems.

4.2.7 NOAA

NOAA performs GPS research and development aimed at (1) improved GPS orbit determination, (2) improved determination of the vertical coordinate using GPS, and (3) development of models of error sources that can improve the accuracy attainable using data from the national CORS network of GPS reference stations. Some of the specific studies being undertaken are: improved modeling of tidal deformations of the Earth; development of models of antenna phase center variation as a function of elevation angle of a satellite; development of models of station specific multipath errors; and development of improved models of geoid height required to convert GPS derived ellipsoid heights to orthometric heights.

NOAA is also developing operational methods of using GPS derived total precipitable water vapor determinations to improve the accuracy of weather forecasts. Studies are underway to improve the methods used to position and orient aircraft performing photogrammetry in support of nautical and aeronautical charting, as well as the positioning of the keel of vessels relative to sea bottom hydrography. The National Polar-orbiting Operational Environmental Satellite System (NPOESS) relies on a GPS occultation sensor to monitor ionospheric electron density profiles and scintillation properties.

NOAA is collaborating with academia in research toward achieving better than 1 cm real-time positioning. Through dual-frequency carrier phase positioning methods, and real-time CORS data (supporting both differential GPS and improved atmospheric models), investigations are underway to achieve 1 cm or better in accuracy over CONUS as close to real time as possible.

4.3 DoD R&D

Joint Precision Approach and Landing System (JPALS) Technology Development

JPALS is based on local area differential GPS. This system is being developed to meet the DoD’s need for an anti-jam, secure, all-weather Category I/II/III aircraft landing system that will be fully interoperable with planned civil systems utilizing similar technology. The equipment supports fixed-base, tactical, special mission, and shipboard applications, and is compatible with civil and military GPS signals.

The JPALS Technology Development phase began in June 2002 with the objective of further reducing the technical risk and defining performance requirements to support a milestone decision in FY 2006 to begin the System Design and Development (SDD) phase.

GPS III

Studies are underway for the next generation of PNT satellites, known as GPS III. These studies are addressing improvements in accuracy, availability and integrity as well as increased anti-jam performance to meet the future needs of civil and military users. One potentially significant improvement is the ability to support navigation for all phases of flight through approaches with vertical guidance without the need for regional augmentation, potentially reducing long-term ownership costs. The first GPS III launch is projected for 2013.

Appendix A

Definitions

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. (Note: Chapter 4 in the FRS discusses chart reference systems and the risks inherent in using charts in conjunction with radionavigation systems.)
- 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.

Air Traffic Control (ATC) - A service operated by appropriate authority to promote the safe and efficient flow of air traffic.

Area Navigation (RNAV) – A method of navigation which permits aircraft operation on any desired flight path within the coverage of station referenced navigation aids or within the limits of capability of self-contained aids, or a combination of these.

Availability - The availability of a navigation system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigation signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Coastal Confluence Zone (CCZ) - Harbor entrance to 50 nautical miles offshore or the edge of the continental shelf (100 fathom curve), whichever is greater.

Common-use Systems - Systems used by both civil and military sectors.

Conterminous U.S. (CONUS) - Forty-eight adjoining states and the District of Columbia.

Continuity - The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation.

Coordinated Universal Time (UTC) - UTC, an atomic time scale, is the basis for civil time. It is occasionally adjusted by one-second increments to ensure that the difference between the uniform time scale, defined by atomic clocks, does not differ from the earth's rotation by more than 0.9 seconds.

COSMIC – The Constellation Observing System for Meteorology, Ionosphere and Climate is scheduled for launch in December 2005 and consists of six microsatellites each carrying three instruments: a GPS radio occultation receiver, an ionospheric photometer, and a tri-band beacon. These satellites will initially be placed in an initial orbit 400 km above the Earth and over the first year will be gradually boosted to a final orbit approximately 700 km above the Earth. During this time geodetic gravity experiments will be conducted.

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 - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

En Route - A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

Full Operational Capability (FOC) - A system dependent state that occurs when the particular system is able to provide all of the services for which it was designed.

Global Navigation Satellite System (GNSS) – GNSS refers collectively to the world-wide positioning, navigation, and timing (PNT) determination capability available from one or more satellite constellations, such as the United States' Global Positioning System (GPS) and the Russian Federation's Global Navigation Satellite System (GLONASS). Each GNSS system employs a constellation of satellites operating in conjunction with a network of ground stations.

GRACE – The Gravity Recover and Climate Experiment consists of two identical satellites launched in March 2002 and flying approximately 220 km apart in a polar orbit 500 km above the Earth. Its primary mission is to conduct gravity field measurements. Each spacecraft carries a Blackjack GPS receiver which, in addition, acquires GPS occultation measurements.

Initial Operational Capability (IOC) - A system dependent state that occurs when the particular system is able to provide a predetermined subset of the services for which it was designed.

Integrity - Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation.

Interference (electromagnetic) - Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the performance of user equipment.

Jamming (electromagnetic) - The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing the effective use of a signal.

Jason – An oceanography satellite launched December 2001 and flying in a 66° inclined orbit 1300 km above the Earth. Its mission is to monitor global ocean circulation, study the ties between the oceans and atmosphere, improved global climate forecasts and predictions, and monitor events such as El Nino conditions and ocean eddies. It is designed to directly measure climate change through very precise millimeter-per-year measurements or global sea-level changes. On-board instrumentation includes a GPS receiver and a laser retoreflector.

Multipath - The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion.

Nanosecond (ns) - One billionth of a second.

National Airspace System (NAS) - The NAS includes U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts and digital navigation data; information and service; rules, regulations and procedures; technical information; and labor and material used to control and/or manage flight activities in airspace under the jurisdiction of the U.S. System components shared jointly with the military are included.

Navigation - The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

NAVTEX – A system designated by IMO as the primary means for transmitting coastal urgent marine safety information to ships worldwide. The NAVTEX system broadcasts Marine Safety Information such as Radio Navigational Warnings, Storm/Gale Warnings, Meteorological Forecasts, Piracy Warnings, and Distress Alerts. Full details of the system can be found in IMO Publication IMO-951E – The NAVTEX Manual.

Nonprecision Approach (NPA) – An instrument approach procedure based on a lateral path and no vertical guide path. The procedure is flown with a navigation system that provides lateral (but not vertical) path deviation guidance.

Precise Time - A time requirement accurate to within 10 milliseconds.

Precision Approach – An instrument approach procedure, based on a lateral path and a vertical glide path, that meets specific requirements established for vertical navigation performance and airport infrastructure.

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

Radiolocation - Radiodetermination used for purposes other than those of radionavigation.

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

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

Required Navigation Performance (RNP) - A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

Surveillance - The observation of an area or space for the purpose of determining the position and movements of craft or vehicles in that area or space.

Surveying - The act of making observations to determine the size and shape, the absolute and/or relative position of points on, above, or below the Earth's surface, the length and direction of a line, the Earth's gravity field, length of the day, etc.

Terminal - A phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Terminal Area - A general term used to describe airspace in which approach control service or airport traffic control service is provided.

World Geodetic System (WGS) - A consistent set of constants and parameters describing the Earth's geometric and physical size and shape, gravity potential and field, and theoretical normal gravity.

Appendix B

Glossary

The following is a listing of abbreviations for organization names and technical terms used in this plan:

ABAS	Aircraft Based Augmentation System
ADS-B	Automatic Dependent Surveillance-Broadcast
AIRSAR	Airborne Synthetic Aperture Radar
AIS	Automatic Identification Systems
ARNS	Aeronautical Radionavigation Service
C/A	Coarse/Acquisition
CFR	Code of Federal Regulations
CJCS	Chairman, Joint Chiefs of Staff
cm	centimeter
CONUS	Conterminous United States
CORS	Continuously Operating Reference Stations
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CRAF	Civil Reserve Air Fleet

DGPS	Differential Global Positioning System
DHS	Department of Homeland Security
DME	Distance Measuring Equipment
DOC	Department of Commerce
DoD	Department of Defense
DOT	Department of Transportation
ECDIS	Electronic Chart Display Information System
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOC	Full Operational Capability
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FRS	Federal Radionavigation Systems
FTA	Federal Transit Administration
GBAS	Ground-Based Augmentation Systems
GDGPS	Global Differential GPS
GEO	Geosynchronous Earth Orbit
GLONASS	Global Navigation Satellite System (Russian Federation System)
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
HA-NDGPS	High Accuracy Nationwide Differential Global Positioning System
HEA	Harbor Entrance and Approach
Hz	Hertz (cycles per second)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities

ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IGEB	Interagency GPS Executive Board
IGS	International GNSS Service
ILS	Instrument Landing System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
INU	Inertial Navigation Units
IOC	Initial Operational Capability
IRAC	Interdepartment Radio Advisory Committee
ITS	Intelligent Transportation Systems
ITS-JPO	Intelligent Transportation Systems Joint Program Office
ITU	International Telecommunication Union
IVI	Intelligent Vehicle Initiative
Jason	See Appendix A
JPALS	Joint Precision Approach and Landing System
JPL	Jet Propulsion Laboratory
JPO	Joint Program Office
km	kilometer
LAAS	Local Area Augmentation System
LGF	LAAS Ground Facility
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical Guidance
m	meter
MARAD	Maritime Administration
MDGPS	Maritime Differential GPS Service
MHz	Megahertz
M-Code	Military Code

MLS	Microwave Landing System
MOA	Memorandum of Agreement
MON	Minimum Operational Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
Navaids	Navigation Aids
NAVTEX	See Appendix A
Navwar	Navigation Warfare
NDB	Nondirectional Beacon
NDGPS	Nationwide Differential Global Positioning Service
NEXCOM	Next Generation Air/Ground Communications
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NHTSA	National Highway Traffic Safety Administration
NII	Networks and Information Integration
NIS	Navigation Information Service
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPA	Nonprecision Approach
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
NTSB	National Transportation Safety Board
OOBE	Out-of-Band Emissions
OST	Office of the Secretary of Transportation
OST/P	Assistant Secretary for Transportation Policy
PNT	Positioning, Navigation, and Timing

PPS	Precise Positioning Service
PTC	Positive Train Control
QZSS	Quasi Zenith Satellite System
R&D	Research & Development
RFI	Radio Frequency Interference
RITA	Research and Innovative Technology Administration
RLS	Radiolocation Service
RLV	Reusable Launch Vehicle
RNAV	Area Navigation
RNP	Required Navigation Performance
RNS	Radionavigation Service
RNSS	Radionavigation Satellite Service
RTCM	Radio Technical Commission for Maritime Services
SA	Selective Availability
SARPs	Standards and Recommended Practices
SATMS	Space and Air Traffic Management System
Satnav	Satellite-Based Navigation
SBAS	Satellite-Based Augmentation System
SBR	Space-Based Range
SDD	System Design and Development
SLSDC	Saint Lawrence Seaway Development Corporation
SPS	Standard Positioning Service
TACAN	Tactical Air Navigation
TASS	TDRSS Augmentation Service Satellites
TDRSS	Tracking and Data Relay Satellite System
TT&C	Telemetry Tracking and Control
UN	United Nations
UNAVCO	University NAVSTAR Consortium
U.S.C.	United States Code

USCG	United States Coast Guard
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
VHF	Very High Frequency
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
WAAS	Wide Area Augmentation System
WGS	World Geodetic System 1984
WRC	World Radiocommunication Conference

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The Federal Radionavigation Plan (FRP) is published in accordance with Section 2281(c) of Title 10, United States Code and delineates policies and plans for radionavigation services provided by the U.S. Government to ensure efficient use of resources and full protection of national interests. Developed jointly by the U.S. Departments of Defense, Transportation, and Homeland Security, the FRP sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

The FRP is updated biennially. This twelfth edition describes respective areas of authority and responsibility, and provides a management structure by which the individual operating agencies will define and meet requirements in a cost-effective manner. Moreover, this edition contains the current policy on the radionavigation systems mix. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues it addresses. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans towards providing an optimum mix of radionavigation systems for the foreseeable future.

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