

Planning the Future of GPS

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BIOGRAPHY

John W. Lavrakas is a Senior Staff Engineer for Overlook Systems Technologies, Inc. where he serves as Director of Operations Support for the Department of Defense GPS Support Center. Prior to this, he conducted the affairs of the Secretariat for the Interagency Forum for Operational Requirements and provided technical analysis support to the Office of Assistant Secretary of Defense/C3I. Mr. Lavrakas has spent the last 22 years in GPS, supporting the development of the GPS Control Segment, GPS user equipment for military range applications, and developing and marketing GPS-based commercial asset location systems. Mr. Lavrakas has written numerous papers and articles on GPS, including those appearing in *GPS World* and *GPS Solutions* magazines. He is a graduate of Harvey Mudd College and the Claremont Graduate University with BS and MA degrees in mathematics.

ABSTRACT*

Within its first two decades GPS has become the premier positioning and timing system worldwide. Although GPS began primarily as a provider of anytime, anywhere positioning and timing service for US military operations, it has evolved into a complex system of systems heavily incorporated into US and international commerce and technology. Because of this complexity however, modernizing GPS poses numerous challenges.

What is the effect of adding a new signal? How will changing an existing signal affect current users? What does backwards compatibility mean to the various applications that use GPS? Should GPS satellites offer more than just positioning and timing? How can international users influence GPS services? What augmentations will be required to support precision services in the next 20 to 30 years? The broad range and technical depth of these questions typify the complexity of the system as it is today.

To add to this complexity, GPS is affected or controlled by numerous organizations. Whether it is the US Department

of Defense and its uniformed services or the numerous civilian agencies, there are many which would influence GPS to accommodate their needs. Achieving some form of consensus on the many issues affecting GPS is indeed a challenge. The representation on GPS's governing board, the Interagency GPS Executive Board, -- consisting of members representing the Departments of Defense, Transportation, Commerce, State, Interior, Justice, and Agriculture, the Joint Chiefs of Staff and NASA, -- exemplifies the multifaceted role GPS plays today.

In order to accommodate these complex issues, the US Government has instituted a number of processes. These include interagency processes to address proposed new operational requirements and interpretation of existing requirements, systems engineering decisions, and architectural decisions for the next generation of GPS satellites and ground control systems.

This paper describes current activities underway that support the future of GPS, and identifies several recent initiatives affecting its future.

WHAT DRIVES THE FUTURE OF GPS?

The Presidential Decision Directive of March 1996 explicitly identified GPS as a positioning and timing service provided by the US Government free of charges to users worldwide. It formalized the interagency control of GPS, assigning this role to both the Departments of Defense and Transportation. Since then, the future of GPS has been initiated by a series of major commitments. These include:

- Development and use of local and wide area augmentations for aviation
- Delineation and funding of two additional civil frequencies, L2 and L5
- Definition of navigation warfare to ensure US military dominance without civil disruption

All of these issues (and more) are instrumental in driving the future of GPS. The author now highlights four key factors that influence this future. See Figure 1.

* This paper expresses the views of the author, and does not represent the official position of any government agency.

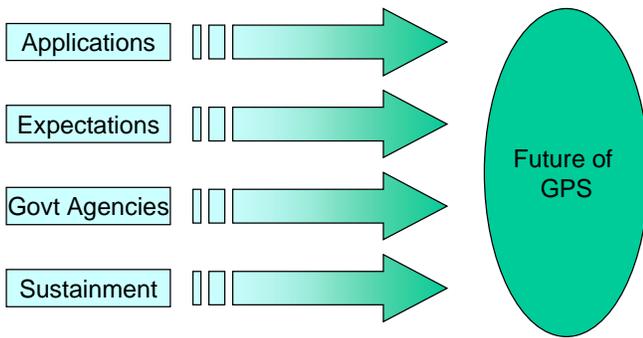


Figure 1. Factors driving the future of GPS

Application Needs

Current and future GPS needs are first and foremost driven by its applications. The military routinely uses GPS for precision targeting, rendezvous, search and rescue, logistics, and precise timing. Not a few military leaders have said that the Operation Enduring Freedom campaign in Afghanistan has largely been effective because of space force enhancement, and in particular GPS. From an application standpoint, if its current capabilities are accuracy, availability, and reliability, then the future needs would obviously include greater accuracy, availability, and reliability.

Likewise civilian uses of GPS abound. For the past decade GPS has infiltrated itself as it were into every civil major infrastructure, including transportation, communications, power, and public safety, not to mention numerous commercial and scientific uses. As with the military, the civilian community demands improved accuracy, availability, and reliability. Furthermore applications such as aviation and marine services demand “integrity”, the ability for the user to determine if the service is producing erroneous information. Many utility services, such as cellular telephone companies, Internet routers, and power companies, have embedded GPS into their operation, and correspondingly need assurances of reliability and accuracy. Emergency services, including ambulance and public safety services, Enhanced-911, and search and rescue teams all regularly rely on GPS for locating victims and maintaining situational awareness of public safety personnel. They demand universality of operation and reliability of service. Even surveying applications expect reliable L1 code and L2 carrier services that will continue uninterrupted for years.

User Expectations

Because GPS is now embedded into the public infrastructure of the United States and numerous other countries, expectations are very high with respect to its security, availability, and reliability. Since the civil service is provided by the United States to users worldwide, it is important that the US Government establish and meet expected levels of performance. This has been done for the past decade by means of the GPS Standard Positioning Service (SPS) Performance Standard (formally SPS Signal Specification) [1].

To some degree GPS has been fortunate in far exceeding original commitments in signal accuracy and availability so that there have not been any significant issues with respect to meeting these commitments. The future is uncertain with respect to this, however, due to rising demands on the service and correspondingly higher expectations. The US Government has not adequately addressed issues of signal monitoring to ensure it meets documented commitments. For example, the C/A signal is not continuously monitored, even though the US commits to its availability and accuracy in the SPS Performance Standard [1].

Government Agencies

The Global Positioning System and its augmentations are controlled by several US Government departments. The Department of Defense is responsible for funding, operating, and sustaining GPS, as well as providing for the needs of authorized military users of GPS. The Department of Transportation is responsible for the civil uses of GPS, as well as funding, operating, and sustaining its civil augmentations. The Department of State is charged with representing the US Government’s position on GPS to the international community.

There are numerous agencies that incorporate GPS into their current and future operations. These include the Federal Aviation Administration (FAA) with its reliance on GPS as an en-route navigation system, the US Coast Guard implementing vessel traffic systems using GPS for harbor entry and inland waterway navigation, the National Aeronautics and Space Administration using GPS for numerous space positioning and attitude determination applications, the Federal Highway and Railroad Administrations each relying on GPS to support major initiatives in safety, and the Departments of Interior and Agriculture using GPS in support of surveying needs. Each department and agency has a unique mission served by GPS, and each has unique desires for the future of GPS.

System Sustainment and Modernization

GPS has been operational for years, and many of its satellites have now exceeded their expected mission duration. For the system to continue to operate in accordance with user expectations, the US Government needs to sustain the satellite constellation and ground segment by replacing older satellites and ground stations. Many changes are planned (and in many cases underway) for the satellites and ground control networks. These include upgrading outdated computer equipment at the Master Control Station, replacing aging GPS receivers at monitor stations, and integrating data from monitor stations operated by the National Imagery and Mapping Agency. The Air Force is planning to implement the autonomous navigation feature on Block IIR satellites, which allows continuous update to the navigation message data without daily control segment contacts. This change

alone could affect GPS performance levels and markedly alter the tempo of satellite operator crews. The GPS Joint Program Office is looking for ways to reduce total ownership costs of GPS by advancing the technology used in satellites and ground control components. In general, sustainment and modernization issues significantly drive future GPS needs.

THE PLANNING PROCESS

With so many factors influencing the future of GPS, it is important to establish a means that ensures all issues are addressed and the resulting service meets the needs of all interested parties. This process must ensure that the new capabilities are activated when they are needed, yet without disrupting existing capabilities.

The process must support existing processes established by the military and civil departments and agencies responsible for acquiring and operating new systems. For example, the US Air Force is responsible for acquiring basic GPS services and the Department of Transportation for acquiring differential GPS services and space and ground based GPS augmentation systems. Any process advancing these capabilities must adhere to the formal processes employed by these two departments. The new process can integrate these processes, but cannot circumvent them or abrogate them.

The process must support the definition and validation of operational requirements. It must ensure that proper systems engineering principles are applied in architecting solutions. It must investigate various options and choose options that are cost effective. It must involve all participating user communities, including commercial, military, governmental, and international. Also, the processes being followed must be known and understood by all players.

Primary Duties

Let’s first take a look at the condition GPS management is in today. At the time of the Presidential Decision Directive (PDD) of 1996, three departments were established to oversee GPS and its augmentations, including acquiring, managing, sustaining, and operating it. An Interagency GPS Executive Board (IGEB) was formed to administer these functions and the IGEB was sized to include all key departments and agencies. Today the IGEB consists of representatives from the Departments of Defense, Transportation, State, Interior, Commerce, Justice, and Agriculture, as well as from the Joint Chiefs of Staff and the National Aeronautics and Space Administration. See Figure 2.

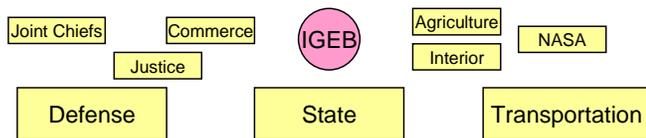


Figure 2. GPS managing departments and agencies

Under the PDD, the State Department is assigned the duties of handling international agreements and relationships with respect to GPS.

The Department of Defense (DoD) is tasked with acquiring, operating, and maintaining the Global Positioning System. The DoD delegated its acquisition and maintenance duties to the US Air Force, which in turn delegated them to Air Force Space Command (AFSPC). AFSPC in turn has tasked the GPS Joint Program Office of the Space and Missile Center to execute this duty.

Likewise the DoD delegated the operational duties to US Space Command, which in turn allocated these to its Air Force component, Space Air Force (SPACEAF). SPACEAF assigns operational duties to fly the satellites to the Second Space Operations Squadron (2SOPS) at Schriever AFB in Colorado. See Figure 3.

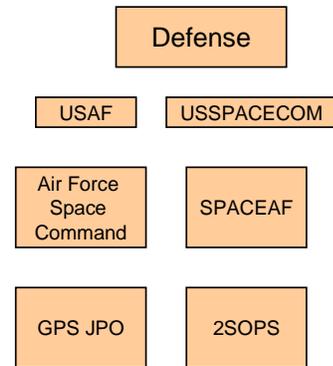


Figure 3. Department of Defense organizations

The Department of Transportation (DOT) is tasked with acquiring, operating and sustaining civil augmentations to GPS as well as providing the US Government interface to civil users of the system. DOT has delegated general civil interface matters along with land and sea augmentations to the US Coast Guard. The Coast Guard has developed and is maintaining the Maritime Differential GPS Service, and is now building out the Nationwide Differential GPS Service. DOT has delegated aviation-related relationships and services to the Federal Aviation Administration. The FAA is in process of developing the Wide Area and Local Area Augmentation Systems. See Figure 4.

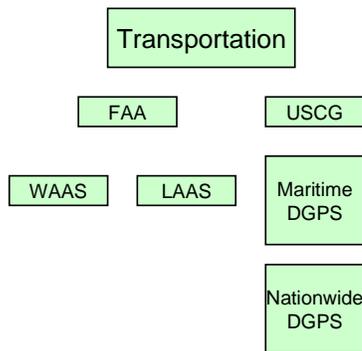


Figure 4. Department of Transportation organizations

To this point we can see at least 20 organizations identified as having responsibility in directing some part of GPS.

Advisory Bodies

A number of advisory bodies have been formed to assist in the wise implementation and use of GPS and its augmentations. To date the following organizations have been formed. See Figure 5.

GPS Interagency Advisory Council (GIAC) – formed by the Department of Commerce to identify and address civil GPS positioning, navigation, and timing issues for Federal agencies and their customers. The GIAC is comprised of representatives from the Departments of Agriculture, Commerce, Defense, Interior, State, and Transportation as well as members of the Environmental Protection Agency, Federal Communications Commission, NASA, National Capitol Planning Commission, and Tennessee Valley Authority.

Civil GPS Service Interface Committee (CGSIC) – coordinated and managed by the US Coast Guard and identifies civil GPS user needs, domestic and international, in support of the Department of Transportation’s program to exchange information concerning GPS with the civil user community.

Satellite Operational Implementation Team (SOIT) – formed by the FAA to assist in the development and use of GPS and its augmentations for aviation applications.

Independent Review Team (IRT) – formed by Air Force Space Command to advise on current and future GPS operational issues.

Independent Assessment Team (IAT) – formed by the IGEB to advise the IGEB on issues related to current and future GPS operations.

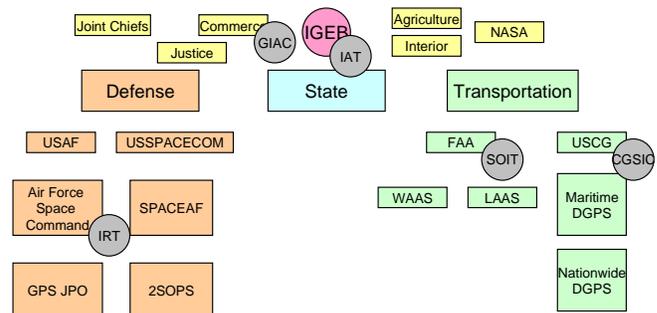


Figure 5. GPS advisory bodies

These bodies, though having no formal authority in the acquisition and operation of GPS and its augmentations, nonetheless heavily influence the future direction of GPS and decisions affecting it. With these additional advisory bodies, we now have at least 25 separate organizations each having a vested interest in current and future GPS functionality and applications.

Making Changes to GPS

With all these various organizations and groups interested in GPS and its future, how does one go about making changes to the system? And how does one bring a new capability on line while maintaining current capability for all users? This becomes a sticky issue, and requires some additional organizational support from the US Government before it can be implemented.

First, let’s look at what key activities are required to implement new capabilities.

Definition of new operational requirements – for a new capability to be incorporated, it needs to be added to the GPS Operational Requirements Document, a document managed by the Air Force that identifies deficiencies in the system. Any new capabilities are inherently “deficiencies” since they do not exist in the current system, and by adding them to the ORD they then become operational requirements that must be implemented.

Definition of concept of operations – GPS user applications each have their own unique ways in which they employ the system. Correspondingly, each has different expectations. These various concepts of operation have to be documented and used in defining future capabilities to ensure that any new capabilities do not adversely affect current operations. For example, providers of the military spot beam service need to define how they will provide this functionality to multiple users requesting it simultaneously, and how to ensure that the capability does not disrupt normal operations outside areas of conflict.

Systems engineering issues – implementing new capabilities can have significant technical impacts to existing services. What is the effect of adding a new signal? How will

changing an existing signal affect current users? What does backwards compatibility mean to the various applications that use GPS? Should GPS satellites offer more than just positioning and timing? For example, adding secondary payloads to GPS satellites, such as a search and rescue capability, may require adding more power to the satellite, necessitate a more powerful launch rocket, or affect constellation management decisions. Likewise adding a civil code to the L2 frequency can affect signal power levels and backwards compatibility with existing receivers.

Interagency Control

With so many organizations interested in new capabilities, the US Government must ensure there are interagency processes to address each of the key activities described above. To this end it has created several formal interagency boards and processes. All GPS policy matters are handled by the Interagency GPS Executive Board, which in turn delegates many of the day to day activities to its Senior Steering Group.

In 2000 an interagency process for operational requirements was developed, called the Interagency Requirements Plan (IRP) [2]. Up until that time, the GPS requirement processes had been separated between a DoD-only process and a DOT-only process. Under the new interagency format, both processes operate side-by-side in a cooperative manner to ensure that both military and civil objectives are met. See Figure 6. This is done by the Interagency Requirements Oversight Committee (IROC), co-chaired by the Vice Chairman of the Joint Chiefs of Staff (VCJCS), and the DOT Assistant Secretary for Policy.

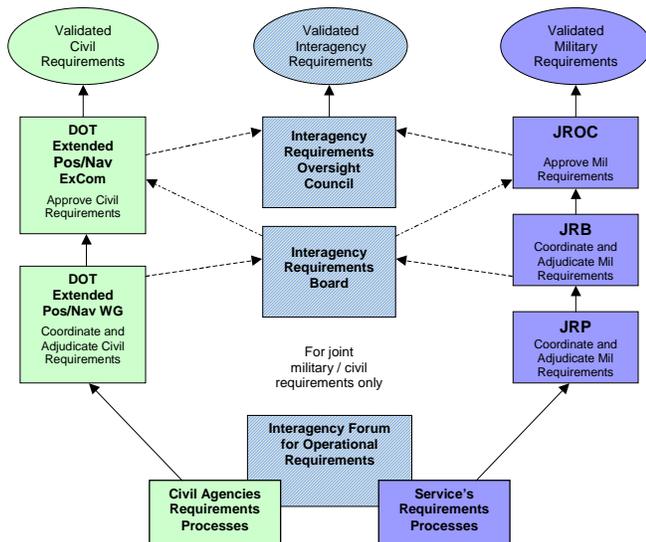


Figure 6. The Interagency Requirements Process

The IRP created a new entity called the Interagency Forum for Operational Requirements (IFOR) to coordinate the definition of requirements at the lowest level, viz., the entry point of requirements into both the military and civil re-

quirements processes. Its purpose is to receive and process new operational requirements, and to respond to requests for clarification on operational requirements identified in the GPS ORD. It consists of representatives from both the military and civil communities, and ensures that proposed new operational requirements address all necessary military and civil issues before they are submitted to their respective processes for validation. The Interagency Requirements Board is established as a review organization for proposed new operational requirements submitted by the IFOR for consideration prior to validation by the IROC.

Systems engineering issues are addressed by the GPS Systems Engineering Forum, consisting of representatives of the GPS Joint Program Office, US Coast Guard, FAA, and NASA [3]. Currently there is no forum to address user concept of operations, so this is being handled by the IFOR member agencies.

Funding of GPS and its augmentations is delegated to two departments, Defense and Transportation. The Department of Defense funds the basic signal-in-space GPS service. The Department of Transportation funds augmentations to GPS, such as the Maritime Differential GPS Service and the Wide Area Augmentation System. Any additional capabilities added to either of these basic services must be funded by the organization adding the requirement.

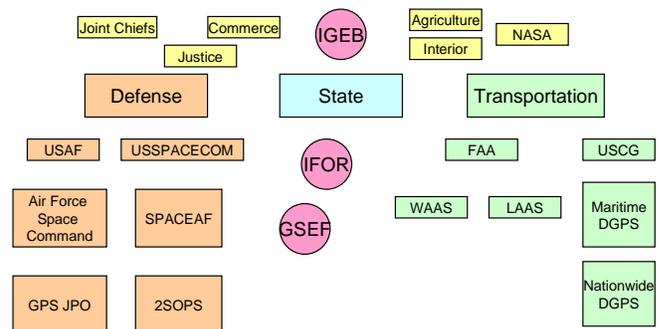


Figure 7. Interagency control boards

In summary, Table 1 identifies each of the primary activities associated with planning the future of GPS, along with its associated organizations. See Figure 7.

Table 1. Planning activity and associated organizations

Activity	Associated Organizations
Policy	IGEB
Future Requirements	IFOR, IRB, IROC, advisory bodies
Architecture	GSEF
Concept of Operations	None. Handled by individual military & civilian organizations
Funding	DoD, DOT, other organizations sponsoring new requirements

RECENT INITIATIVES

For the past several years GPS member departments and agencies, along with associated interagency groups, have been actively pursuing matters affecting the future of GPS. Some recent initiatives are summarized in sections following.

Interagency GPS Executive Board

The IGEB has been active in protecting current and future use of the GPS spectrum, engaging with Federal agencies and the US Congress on key GPS matters, and sponsoring projects that investigate issues that consider future requirements for GPS users

- Submitted formal comments to the FCC on proposed access to GPS spectrum by ultra-wideband (UWB) technology (October 2001)
- Sponsored a GPS industry fair on Capitol Hill (June 2000)
- Annually the IGEB Senior Steering Group reviews and funds projects that support interagency initiatives related to GPS, including funding for the GPS Support Center, global dual monitoring system studies, and integrity failure mode effects analysis.

Interagency Forum for Operational Requirements

The IFOR has held numerous meetings with member agencies and departments in 2001 and 2002, collecting proposed new operational requirements for future position, navigation and timing for inclusion in the GPS Operational Requirements Document.

GPS Systems Engineering Forum

- GSEF Formed (December 2001)
- Held meetings to discuss topics related to spectrum, augmentations, and civil frequencies (2001-2002)

Department of Defense

The DoD has actively pursued navigation warfare studies, current performance commitments, and GPS modernization.

- Completed navigation warfare analysis of alternatives (2000)
- Issued SPS Performance Standard (October 2001)
- The GPS Joint Program Office has actively taken steps to implement the GPS III program
 - Contracted for studies on candidate architectures (2000-2001)
 - Solicited civil users for inputs (2001)
 - Invited public comments to ICD-GPS-200C (April 2001)
- Developed and validated the GPS Operational Requirements Document (February 2000)
- Actively updating the GPS ORD to reflect new military and civil needs (2000-2002)
- Jointly issued update to Federal Radionavigation Plan with DOT (2001)

- Jointly held public forum with DOT on L2/L5 (June 2001)

Department of Transportation

The DOT has actively pursued current performance commitments, supported interactions with domestic and international civil GPS users, and investigated GPS modernization issues.

- Held semiannual meetings of the Civil GPS Service Interface Committee
- The FAA has reviewed various GPS architectures for aviation needs (2001-2002)
- Jointly issued update to Federal Radionavigation Plan with DoD (2001)
- Jointly held public forum with DoD on L2/L5 (June 2001)

Department of State

The Department of State continues to represent the US Government in protecting GPS spectrum and to solicit inputs from other nations on improving GPS.

- Issued U.S. position on Galileo (March 2002)
- Participated in World Radionavigation Council meetings (2001)
- Issued *demarche* soliciting recommended changes to GPS from GPS user nations (July 2001)

White House

The White House terminated selective availability (May 2000).

ISSUES AND CONCERNS

From the foregoing, we see that the process of moving into the future of GPS is not without difficulty. The author identifies several significant issues to be considered.

- “Too many cooks in the kitchen” – The nature of the interagency process for development and operation of GPS practically guarantees there will be many organizations directing, guiding, and influencing its future. With such an arrangement, even though interagency processes ensure consensus on key issues, they often fail to provide necessary leadership. Organizations assigned charge of individual activities (acquisition of basic GPS, acquisition of augmentations, operation of current GPS, and so on) tend more to follow the direction of their parent organizations than conforming to the vision of a single authority. Interaction between agencies and departments is cumbersome, and communication and direction are often incomplete or unclear.
- Thinned down resources – With so many organizations involved in GPS, and each having to provide sufficient expertise to support its own organization, the GPS talent pool tends to become diluted and spread out. Few organizations have the budget to maintain continued

expertise needed to sustain current service and to make critical decisions necessary to take GPS into the future. For example, the GPS Joint Program Office and the FAA retain sizeable staffs with GPS expertise to support current and future initiatives, while the Department of State, Air Force Space Command, and numerous civil departments cannot afford the staff needed to support their missions. Often these staffs must deal with GPS as only one of several programs they must support. The result is that when interagency meetings are held, the decisions made are largely influenced by the more affluent organizations.

- Lack of strategic thinking – Planning the future is a difficult business. To be able to look not just two or five years out, but 20 to 30 years is difficult for many. To formulate options, to assess the cost and benefit of these options, to restructure budget priorities to fund cost effective solutions, and so on, takes time and can be very resource intensive. To date, few GPS user agencies and departments have been able to accomplish this. The extent of their investigation is merely to consider the benefits that an improved GPS can provide them over the next five to ten years at best. In many cases they just ask for improved accuracy, availability, reliability, and integrity, not knowing how much to ask for or unable to assess quantitatively what an improved capability will do for them.

SUMMARY

Movement towards the future of GPS is well underway. This has in large part been forced by several key initiatives promulgated by the US Government, including two additional civil frequencies, the navigation warfare initiative, and civil augmentations. The process by which GPS moves into the future is heavily influenced by a number of factors, including the applications themselves, expectations of current users, the objectives and goals of US Government departments and agencies, and pragmatic needs to sustain the system.

Many military and civil organizations actively apply resources to support the future of GPS, albeit for their own organizational objectives. In order to consolidate the various objectives and implementation approaches of these organizations, interagency groups have been created. These interagency groups, while bringing cohesion to the process, also introduce added interfaces, priorities, costs and objectives, resulting in delays and mismatched goals.

Planning the future of GPS is a complex process that is designed to recognize and incorporate the interests of its total user base. Progress will be slow, and it will be arduous. The hope is, however, the result will be a system that indeed incorporates the operational requirements of all participating players, a modernized GPS that is cheaper and easier to op-

erate and provides better service, in accuracy, availability, reliability, and integrity.

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