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Report to Congressional Requesters

September 1994

GLOBAL POSITIONING TECHNOLOGY

Opportunities for Greater Federal Agency Joint Development and Use



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Resources, Community, and
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September 28, 1994

The Honorable Norman Y. Mineta
Chairman
The Honorable Bud Shuster
Ranking Minority Member
Committee on Public Works and Transportation
House of Representatives

Recent technology has made it possible to greatly improve the accuracy of global positioning information available from satellites. This technology, called Differential Global Positioning Systems, or DGPS, allows pilots, surveyors, and others using satellite positioning information for civil uses¹ to determine their position on earth to within a few meters—or even a few centimeters. Many civilian federal agencies are actively pursuing the use of this technology. For example, to improve aircraft navigation and landings, the Federal Aviation Administration (FAA) is planning a national DGPS network costing about \$500 million.

In response to your request of July 21, 1993, we performed a review to determine whether federal agencies are taking full advantage of opportunities to share or jointly develop their systems so as to minimize the cost to taxpayers. Specifically, we focused on (1) the extent to which agencies have been developing joint systems or sharing equipment and (2) additional steps that may be needed to enhance joint development or sharing of DGPS equipment, facilities, and information.

Results in Brief

Between 1988, when federal agencies began to use differential global positioning system technology, and 1993, few federal agencies were developing joint systems or sharing equipment. To a large extent, this early lack of coordination is not surprising. Agencies differed in the applications they were trying to develop, and the federal government had no clear mechanism to coordinate interagency efforts. Beginning in 1993, agencies changed this approach in two ways. First, two agencies developing large-scale systems—the Coast Guard and Federal Aviation Administration—changed their systems to make them easier for other agencies to use. Second, the Departments of Defense and Transportation formed a task force to study global positioning issues, including options for greater joint development or use of differential global positioning

¹Our review focused on civil use of global positioning system technology. The Department of Defense operates the global positioning system and does not use DGPS technology for military operations.

system technology by civilian agencies—at least on a voluntary basis. However, the interagency coordinating mechanisms proposed by the task force and now being put in place have no authority over civilian agencies outside the Department of Transportation. This limited authority leaves other civilian agencies free to develop systems on their own.

The rapid growth in government-sponsored differential global positioning system applications is expected to continue. Such growth and the potentially significant budget implications it carries heighten the need for effective governmentwide coordination. Continuing efforts are under way to address the technical aspects of such coordination—for example, development of standards to ensure that various differential global positioning system applications can use the same equipment. However, these efforts address technical issues only—not issues related to ensuring that agencies will agree to coordinate their development and use of differential global positioning systems.

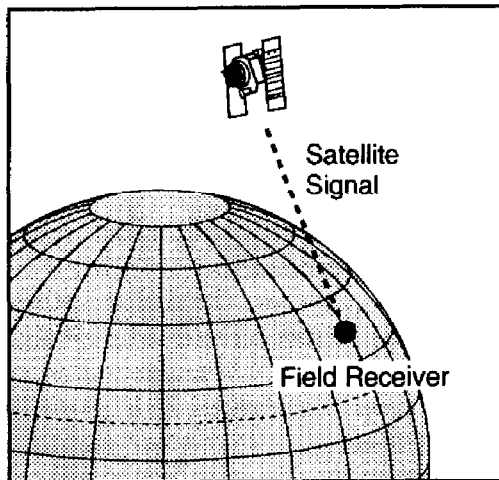
Background

Global positioning information comes from a network of 24 Department of Defense (DOD) satellites. Planes, boats, vehicles, and mapping and survey teams can determine their position on earth by using equipment that receives and interprets signals from these satellites. For civil applications, the satellites provide a signal that is accurate to about 100 meters without the use of DGPS.

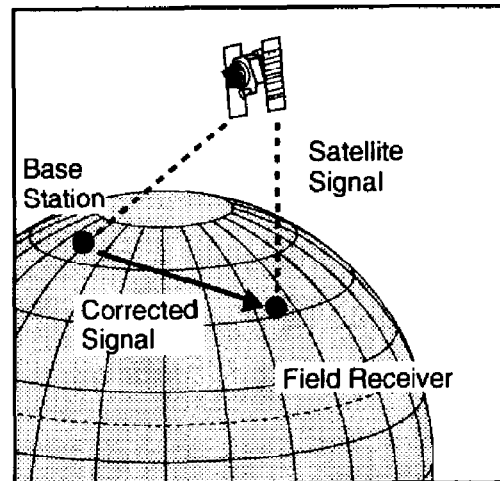
DGPS is a technology for improving the accuracy of this positioning information. This greater accuracy is potentially useful in such ways as improving the accuracy of maps, enhancing search and rescue efforts, improving navigation in crowded waterways, and helping planes land in bad weather. DGPS increases the accuracy of the satellite signal through the use of earth-located “base” or “reference” stations (see fig. 1). The cost of these base stations varies from about \$10,000 to \$200,000 depending on the type of application and communication link needed to get the information to the user. Other costs are for acquiring field receivers that can capture the signals from satellites and base stations and for monitoring and maintaining the equipment and the data it generates.

Figure 1: Basic Components of DGPS

How DGPS Works

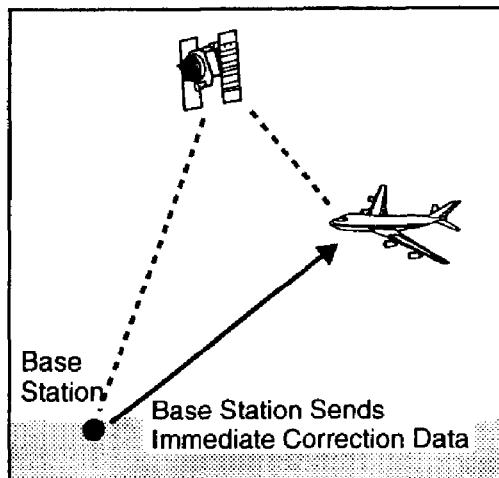


Before DGPS, positioning information from satellites is accurate to about 100 meters.

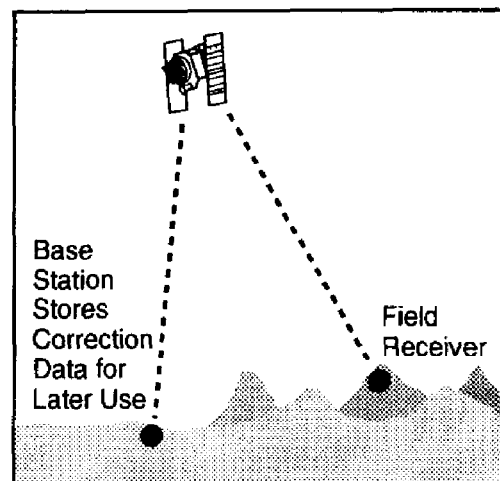


To make the positioning information more accurate, DGPS adds a base station that refines the satellite signal.

Primary Types of DGPS Applications



For navigational purposes, aircraft, ships, or vehicles need immediate information on their location. This kind of DGPS application is called "real-time."



Surveyors and mapmakers can use more accurate positioning information at a later time. For this kind of application, called "post-processing," the base station stores the positioning data for subsequent retrieval.

Note: Positioning data is needed from at least four satellites to determine the three-dimensional position on earth.

DGPS takes two main forms, each with its own equipment requirements. One form, called real-time, transmits positioning information instantaneously to the user, while the second form, called post-processing, stores the information for later use. Real-time has been used largely for navigation, and post-processing has been used mainly for mapping and surveying. Costs are higher for equipment and operations related to real-time than for post-processing.

DGPS development is still considered to be in its infancy. One of the first federal applications was a system installed by the U.S. Forest Service in 1988 for managing forest resources. While usage in both the government and the private sector has mushroomed since that time, global positioning system industry officials estimate that about 95 percent of the market remains to be tapped. They expect DGPS to be commonplace for such additional activities as responding to medical and police emergencies, locating and tracking vehicles, and installing utility services. This continued growth means that the federal investment in DGPS technology—already more than \$518 million through fiscal year 1998—can be expected for some time to come.

Several Factors Contributed to Limited Coordination During Early Development of DGPS

Most DGPS applications within the federal government before 1993 focused on single-agency systems. We reviewed the activities of nine federal agencies that had been active in designing or implementing DGPS applications during this period.² (Table 1 shows the nine agencies and the kinds of applications they were developing. For additional details on each agency's plans, see app. I.) Eight of the nine began their efforts by designing or implementing a single-agency approach. In other words, each agency planned to acquire its own equipment, including base stations, and to set up the system to meet specific agency needs.

²We contacted 13 federal agencies that were involved in transportation, surveying, or mapping—the activities supported by DGPS. Nine of them indicated they had been actively designing, implementing, or operating DGPS applications.

Table 1: Agency DGPS Applications

Agency	Principal DGPS application			
	Navigation		Surveying and mapping	Other
	Aviation	Marine		
Federal Aviation Administration	X			
Coast Guard		X		X ^a
Environmental Protection Agency			X	
Bureau of Land Management			X	
Forest Service			X	
U.S. Geological Survey			X	
St. Lawrence Seaway Development Corporation				X ^a
National Oceanic and Atmospheric Administration			X	
Army Corps of Engineers		X		X ^a

^aIncludes buoy setting and/or dredging.

The one exception to this single-agency approach was the National Oceanic and Atmospheric Administration's (NOAA). NOAA lacked the funds to build its own system but was able to use the Coast Guard's equipment to supply its information requirements. (We will discuss the NOAA-Coast Guard effort in more detail later in this report.)

In many respects, it is not surprising that joint development of DGPS applications was initially limited. One main reason was that the type of application and geographic coverage varied considerably. For example, the Coast Guard and FAA had navigation applications, but the Coast Guard's was for marine navigation largely along the coast and in the Great Lakes, while FAA's was for aircraft navigation throughout the country. Many other agencies had nonnavigational applications, such as surveying and mapping, which required a different kind of system (post-processing rather than real-time) and which often focused on those areas of the country they were responsible for managing.

Even when agencies had similar DGPS needs and applications, other factors often limited the amount of joint development that could occur. These factors related both to the operation of the system and to a limited opportunity or need to coordinate with other agencies.

Incompatible Equipment and Inconsistent Operating Procedures

Single-agency applications developed for mapping, surveying, and related uses sometimes could not share information with other applications because equipment was incompatible. Equipment developed by one manufacturer can have software programs or data-storing formats that cannot be used by another manufacturer's equipment. For example, a Bureau of Land Management (BLM) official said several other agencies stopped trying to access information from a BLM base station because of the time needed to resolve equipment incompatibility problems. Similarly, several agencies were unsuccessful in accessing Forest Service data relating to the locations of streams, bridges, and other features because of computer hardware and DGPS data format limitations. Although a common data format (called Receiver Independent Exchange, or RINEX) had been developed that would allow field receivers made by one manufacturer to share data with post-processing base stations from another manufacturer, several studies conducted during 1991-94 indicated that some manufacturers do not always adhere to this format.

Another information-sharing problem stemmed from differences in agency operating procedures. For functions like mapping and surveying, during which positioning data are collected and stored for later use, agencies establish specific time intervals at which the base station will collect signals from the global positioning satellites. However, these intervals may vary within and between agencies, meaning that positioning data collected and stored to support one application may not support another agency's application. Also, the hours when equipment was available and operating varied. For example, some BLM offices operated their base stations 12 hours a day, 3 days a week, while others operated 12 to 24 hours a day, 5 or 7 days a week. The St. Lawrence Seaway Development Corporation operated its equipment only for short periods of time when the agency was positioning buoys. Finally, the length of time an agency will archive the positioning data ranged from about 2 weeks to permanently. Officials with three agencies said they were reluctant to use DGPS data from other agencies unless they had assurance that the data would be archived long enough to resolve questions that might arise after a project was finished.

Limited Information About Other Agencies' Efforts

Many agency officials said they were unaware of what other agencies were doing and did not know where to go to find out. For some agencies, this situation may not have changed. For example, during our review we spoke with an Environmental Protection Agency (EPA) official in Chicago who wanted to implement DGPS for his region. The official was unaware that the Coast Guard had a base station in Milwaukee, about 90 miles away, and

was planning to put in additional base stations on the Mississippi River that could serve his region. After we informed him about the Coast Guard's equipment, he said he planned to investigate its possible use.

Some attempts at providing information had been made, but they were split between several sources, and the information available was largely incomplete:

- In 1992, the Federal Geographic Data Committee, an interagency body responsible for coordinating all mapping and surveying activity, established a subcommittee that maintained a list of federal, state, and private-sector DGPS base stations, but the list was incomplete.
- In 1989, the Coast Guard established a committee to provide a forum for public- and private-sector users to exchange technical information about the global positioning system, but the committee did not maintain data on the location and characteristics of federal DGPS facilities or capabilities. Since 1990, the Coast Guard has also operated a center that provides information on the status and operational condition of the global positioning system satellites and other related navigation systems, but this center does not provide information about federal DGPS facilities.

Few Incentives for Joint Development

Agencies with systems already under way had little incentive to share information about their systems with other agencies. Several agency officials said coordinating DGPS activities with other agencies requires additional work and expense and can delay the development and implementation of an individual agency's DGPS applications. Agencies also indicated that, besides the initial development's being affected, the ongoing operation of the system could also be adversely affected because of the additional drain on resources. For example, a Forest Service official said his office lacked the staff to provide technical assistance and support to agencies unfamiliar with DGPS applications. As a result, his office stopped sharing DGPS data unless the other agency agreed to share data in return. A BLM headquarters official said that because equipment is often not designed for multiagency use, agency personnel in the field are reluctant to spend the additional time and resources needed to make DGPS equipment or data available to other agencies.

Lacking any governmentwide requirements or policies on how they should develop their DGPS applications, agencies established their own policies and procedures for operating the equipment and sharing the data with other agencies. The differences in procedures sometimes extended to individual

offices within an agency. For example, a Forest Service office in one region of the country has an interagency agreement with a nearby BLM office to share DGPS data, while Forest Service offices in other regions restricted access to DGPS data in order to safeguard the integrity of other sensitive information stored on the same computer system. Several EPA regions established an ad hoc committee to coordinate the development and implementation of DGPS because they had not received any guidance from their headquarters office.

Amid Growing Concern, Steps Were Taken to Improve Coordination and Joint Use

Several agency officials and DGPS experts we contacted³ noted that the development of additional DGPSs or purchase of additional DGPS equipment by federal agencies was increasing the potential for overlap and duplication and that some had already occurred. For example, the Forest Service and BLM installed 11 base stations in Arizona and New Mexico—6 for the Forest Service, 5 for BLM, and according to agency officials, both agencies basically use the same positioning data for mapping and natural resource inventory applications and have the same type of DGPS equipment. DGPS experts said that to meet positioning requirements for resource management applications, only one or two DGPS base stations are needed within most states. Forest Service and BLM officials agreed that some of their base stations overlap and duplicate one another, yet BLM is planning to install four more in these two states because of difficulties in obtaining ready access to the Forest Service's DGPS equipment.

In 1993, anticipating the expected future growth in DGPS, some federal agencies took steps to facilitate greater joint development of DGPS capabilities. These steps fell into two categories: modifying DGPSs to accommodate the needs of other agencies, and examining issues related to greater interagency coordination of DGPS applications.

Modifying DGPSs for Multi-Agency Use

We identified three instances in which agencies had modified or were modifying their DGPS equipment or systems to accommodate joint use.

- To accommodate NOAA's mapping and surveying requirements, the Coast Guard acquired dual-frequency base stations instead of single-frequency ones. NOAA contacted the Coast Guard because it did not have the resources to set up its own system. However, NOAA's surveying and mapping needs required dual-frequency equipment in order to provide

³We discussed DGPS developments with industry and federal agency officials with technical knowledge of DGPS and/or responsibilities for designing and implementing DGPS programs. See app. II for a list of the officials contacted.

greater accuracy than the Coast Guard's planned single-frequency equipment would provide. Such equipment was more expensive than what the Coast Guard initially planned to buy and had funds to pay for. When the equipment dropped in price, however, the Coast Guard was able to obtain the more sophisticated equipment within the amount originally budgeted for the system. In return for the Coast Guard upgrading its DGPS base station equipment, NOAA has agreed to perform the geodetic surveying needed to install the base station equipment.

- The Office of Management and Budget (OMB) asked the Army Corps of Engineers, in lieu of developing a separate DGPS in the lower Mississippi River Valley, to determine whether the Coast Guard's system would meet its needs for surveying and mapping information for dredging, levee construction, and other related activities on the river. Corps officials said they were reluctant at first to pursue a joint venture because of concerns that the Coast Guard's system, which was designed to meet navigational needs, would not provide data sufficiently accurate for dredging and hydrographic surveying purposes. However, after testing an enhanced version of the Coast Guard's system, Corps officials found it could meet their needs. In 1994, the Corps adapted its plans so that it could use the Coast Guard's system and expand it to cover inland waterways rather than build a separate system.
- To accommodate a request by NOAA's National Geodetic Survey (NGS) for additional DGPS base stations for precise mapping and surveying, FAA modified its Wide Area Augmentation System for aviation navigation. Each FAA base station will be equipped with computer and telecommunications equipment to meet NGS' mapping and surveying needs as well as to provide the navigation information for which the system was initially designed. FAA's modifications will also allow other agencies to use its system.

Substantial dollar savings will result from these examples of joint use. A NOAA official anticipates that NOAA's use of the Coast Guard and FAA systems will save about \$10 million in equipment costs alone, and perhaps millions in operating costs over the life of the project. The Corps of Engineers expects to save \$25 million to \$40 million over 5 years by avoiding the need to spend money for equipment, installation, operation, and maintenance of conventional microwave or other systems for dredging and surveying. Savings of this magnitude are even more significant considering that the initial expense for the Coast Guard's system being used by the Corps was \$17.8 million. Corps and Coast Guard officials also believe using a common system will enhance operational efficiencies and marine safety.

Task Force on Joint Development and Use of DGPS

In early 1993, with both military and civil use of the global positioning system growing, concerns were expressed about how best to balance these competing needs while encouraging maximum civil use of the system. In May 1993, DOD and the Department of Transportation (DOT) formed a task force to review these DGPS issues.⁴ In a December 1993 report, the task force concluded that continuing the current ad hoc approach to DGPS development would likely result in unnecessary duplication. To resolve some of the barriers that impede joint development and use, the task force made several recommendations, including the following:

- Reorganizing the civil federal global positioning system management structure established in the 1987 memorandum of agreement by (1) elevating DGPS decision-making within DOT to the assistant secretary level; (2) expanding the former DOT Navigation Council into a new Positioning/Navigation Executive Committee made up of representatives of DOT agencies; and (3) creating an interagency advisory council that would represent to the Executive Committee those agencies primarily interested in DGPS for nonnavigational purposes, such as surveying and mapping. DOT has since begun to implement this structure.
- Conducting an additional study to determine the feasibility of developing a nationally integrated augmented system providing DGPS services for aviation, marine, and land users. This augmentation study, scheduled for completion in 1994, will examine existing and planned federal agencies' DGPS applications and determine the technical feasibility of developing common equipment standards and communication formats suitable for use by multiple DGPS users. However, (as discussed below) the augmentation study will not address the organizational structure necessary to implement this system and ensure governmentwide coordination concerning DGPS.

⁴In 1987, through a memorandum of agreement with DOD, DOT agreed to serve as the primary interface within the U.S. government for all civil global positioning system matters. Within DOT, requirements for transportation were coordinated through the DOT Navigation Council. Input from non-DOT agencies and other civil users of the global positioning system was provided to the Navigation Council through a separate committee sponsored jointly by the Coast Guard and DOT's Research and Special Programs Administration.

Improved Coordination Important, but Steps to Date Are Neither Complete Nor Sufficient

The growth in government-sponsored DGPS applications is expected to continue. The budgetary implications involved in designing new systems, acquiring equipment, and administering DGPS applications over time will increase the need to improve coordination in the years to come. However, it is doubtful that the management structure being set in place as a result of the DOD-DOT task force's recommendations will be adequate to achieve full governmentwide coordination of all DGPS users.

Substantial Growth Expected in Federally Sponsored DGPS Activities

The need for improved coordination can be seen in the anticipated growth of DGPS. In the near term, the federal investment for DGPS is sizeable. For example, FAA's Wide Area Augmentation System alone is expected to cost about \$500 million during 1995-2000, and the Coast Guard plans to spend about \$18 million for its DGPS network, most of this in 1994-95. These expenditures center on (1) an FAA network of up to 33 base stations throughout the entire United States⁵ and (2) a Coast Guard system of 63 base stations along the coastal United States and Mississippi River basin. According to several experts we contacted, once these systems are in place, the substantial infrastructure of base stations could potentially meet the needs of many federal and other DGPS users. (See app. I for a description of the capabilities of these systems.)

The growth in federally owned or federally sponsored DGPS applications is not expected to stop once the systems currently being planned or implemented are in place. Many of the nine agencies we reviewed are planning other applications for the future, and other agencies are likely to follow. At least 15 other federal agencies have identified future DGPS applications, according to an official conducting the DGPS augmentation study. Officials at most federal agencies we contacted said that, because some key applications were still undergoing research and development or operational testing, they had not quantified planned expenditures for some future applications.

The following examples from the nation's highway and rail transportation systems as well as natural resource agencies' applications illustrate some of the potential DGPS expansion in which the federal government will likely be involved:

⁵FAA also plans to have a network of base stations at up to 701 airports to provide greater accuracy needed for precision landings. The cost of this system, much of which will be borne by local airports, is not part of the \$500 million estimate for FAA's Wide Area Augmentation System.

- For highways, DGPS will play an increasing role in some key applications of the Intelligent Vehicle Highway System.⁶ Several demonstration projects are under way to test the feasibility of using DGPS for automatic vehicle location, in-car navigation, and commercial vehicle routing and scheduling. For example, such private sector companies such as Southeastern Freight Lines and the J.B. Hunt trucking company expect to use DGPS to improve vehicle tracking, scheduling, and maintenance, according to an American Trucking Association official. The global positioning system industry projects the market for such applications to be about \$2 billion to \$5 billion by the year 2000.
- For rail systems, the Federal Railroad Administration expects that rail companies will be able to use DGPS to monitor the speed and location of trains and thereby increase the safety and efficiency of rail traffic routing. Burlington Northern and Union Pacific railroads plan to test DGPS as part of a Positive Train Separation system to monitor the speed and location of trains.
- The National Park Service, the U.S. Fish and Wildlife Service, and other federal natural resource agencies plan greater use of DGPS for mapping and various natural resource inventory activities. Use of DGPS is more reliable and much less expensive than traditional surveying methods, which typically require that survey crews spend days or weeks, often in remote areas, in order to inventory wetlands, timber stands, or other resources. The prospect of real-time DGPS-assisted aerial photography will also provide efficiencies by lessening the need for ground-based personnel used to set out visual markers as reference points, according to a Forest Service official.

Growth is also expected in state and local government activities that receive federal support, such as highway construction and mass transit applications. For example, with funding from the Federal-Aid Highway Trust Fund, the Tennessee and Kentucky departments of transportation have installed base stations and other equipment to produce highway maps for transportation planning. Transit authorities in Milwaukee and Denver have spent \$8.3 million and \$11 million, respectively, on DGPS-based vehicle location systems to increase the safety and efficiency of transit bus fleet management. According to a Federal Transit Administration official, other transit agencies around the country are considering installing similar bus tracking systems, which are 80 percent

⁶The Intelligent Vehicle Highway System involves the integration of electronics, communications, computer and control systems into both vehicles and highways and is designed to enhance transportation mobility, energy efficiency, and environmental protection. We recently testified on the progress DOT has made on this system (Smart Highways: Challenges Facing DOT's Intelligent Vehicle Highway Systems Program [GAO/T-RCED-94-253, June 29, 1994]).

federally funded. Neither the Federal Highway Administration nor the Federal Transit Administration requires that such federally funded DGPS applications be coordinated with other federal DGPS applications.

Additional Actions Would Strengthen Interagency Coordination

While these developments underscore the desirability of greater coordination, the mechanisms set in place as a result of the DOD-DOT task force's recommendations are not sufficient to accomplish this task. If the augmentation study being conducted as a follow-up to the task force's work finds that a common network of base stations can be established for joint use, it is critical that an effective mechanism be in place to coordinate subsequent development of DGPS applications. However, the current mechanism does not have authority over many agencies that use DGPS.

Full coordination of DGPS applications essentially requires establishing a clear bridge between two categories of DGPS users—those who use it for real-time navigation and those who use it for post-processing applications such as surveying, mapping, and related purposes. Federal agencies in the first category are DOT agencies such as FAA and the Coast Guard that, under the reorganized management structure now being put in place, are coordinated through DOT's Positioning/Navigation Executive Committee. Federal agencies in the second category are non-DOT agencies such as NOAA, the Forest Service, and the U.S. Geological Survey that are coordinated through the Federal Geographic Data Committee, the separate group responsible for interagency use of spatial data for surveying and mapping. Thus far in the development of DGPS applications, there has been progress in establishing formal mechanisms for DGPS issues between these two groups. However, substantial efforts will be required to achieve full governmentwide coordination.

Each of these categories of user agencies has improved coordination within its own group, but coordination between the two sets of agencies has not significantly changed. For example, after the December 1993 report by the DOD-DOT task force, the Federal Geographic Data Committee made its own proposal for a consolidated DGPS network for mapping, surveying, and related uses. Under the proposal, any federal agency involved in surveying or mapping applications of DGPS or any federally funded application related to such applications would be required to use this network. According to a committee official, the committee withdrew the proposal when DOT expressed concerns that creation of such a network would be premature because the technical feasibility of creating a

network that could be used both for navigation and for surveying and mapping applications was still being studied.

In our view, the organizational structure that has been put in place as a result of the task force's recommendations does not take both user groups equally into account. Under this structure, formulating policy for all civil DGPS applications will rest with the DOT Positioning/Navigation Executive Committee. Linkage with the surveying, mapping, and other applications of non-DOT agencies—such as those coordinated through the Federal Geographic Data Committee—is through a separate Interagency Advisory Council, which is composed of representatives from non-DOT agencies and reports to the Positioning/Navigation Executive Committee. Thus, while non-DOT agencies would have an opportunity to provide their views, decisions would ultimately be made by a committee composed solely of DOT representatives.

It is understandable that the task force did not propose a coordinating body that included non-DOT agencies because DOT has never received executive or legislative branch authority to coordinate non-DOT agencies' use of DGPS. Although DOT has agreed with DOD to serve as the point of contact for all civil applications of the global positioning system, neither the administration nor the Congress has expressly designated DOT as having authority over potential DGPS applications of non-DOT agencies. Thus, while the Positioning/Navigation Executive Committee may be able to set policy for DOT agencies on navigational uses of DGPS, its authority over non-DOT agencies is open to question.

The Positioning/Navigation Executive Committee has been attempting to develop memorandums of agreement between DOT and non-DOT agencies as a way of facilitating greater interagency development and use of DGPS. For example, the joint-use projects described above between the Coast Guard and the Corps of Engineers and the National Geodetic Survey were carried out under these memorandums. According to DOT officials, such memorandums have been helpful in structuring the conditions and costs associated with interagency use of DGPS equipment and information.

Even if such agreements are established, however, such an agency-by-agency approach does not ensure that federal agencies, or others receiving federal funds for DGPS applications, would not buy their own equipment instead of using the available equipment and facilities. For example, if the task force and DOT decisionmakers conclude that a nationwide system of base stations could be used by most or all federally

owned and federally sponsored DGPS applications, the Positioning/Navigation Executive Committee has no authority to require non-DOT agencies to even study the possibility of using the system for future applications.

OMB appears to be the federal agency in the best position to resolve this problem, since it is the executive branch agency responsible for developing governmentwide coordinative mechanisms. As such, OMB is the logical choice to develop interagency policies to promote interagency cooperation concerning joint DGPS development and use. In addition, OMB's budget review process offers another potential opportunity to help ensure that all agencies examine the alternative of using existing equipment and facilities before proceeding with an agency-specific—and potentially duplicative—system. This coordination has already occurred to a limited extent. At the nine agencies we reviewed, one of the instances in which interagency coordination has led to budgetary savings was prompted by questions raised during budget review by OMB. As discussed above, the Corps of Engineers had initially intended to fund its own system, but OMB recommended that the Corps investigate joint use of the Coast Guard's system.

Thus far, no specific requirement exists for agencies to take such steps as a prerequisite to submitting budget proposals for new DGPS applications or for funding DGPS applications by state or local governments. Our discussions with OMB personnel indicated that although some budget examiners had raised issues about DGPS applications in individual circumstances, the effort was not uniformly enforced across the many federal agencies involved in developing or funding DGPS applications. Given that the existing mechanisms for cooperation and coordination are voluntary in nature for most federal agencies, a formal check of this kind may be an appropriate way to ensure a cost-effective approach to DGPS. It would still allow agencies to develop agency-specific DGPS applications, provided the unique requirements of such systems could not be met by the existing federal DGPS infrastructure.

Conclusions

In the past, agencies have not coordinated their efforts to develop DGPS, and this has led to some duplication of facilities and equipment. Since early 1993, coordination has improved, resulting in significant cost savings. However, these instances of coordination were ad hoc efforts. Growing evidence indicates that an agency-by-agency approach to planning and installing DGPS applications may continue to result in

duplication and unnecessary expense. The work of the DOD-DOT task force represents the strongest effort to date to develop a more coordinated, systematic approach to managing the growing demands for DGPS. We believe, however, that the approach that has resulted for coordinating DGPSS and DGPS applications across agency lines is insufficient. It does not ensure that all federal agencies will first look to jointly use the substantial existing and planned infrastructure of DGPS equipment and facilities before designing systems solely to meet their individual needs. Ongoing DOD-DOT efforts to address technical and equipment compatibility issues do not address the issues of interagency coordination. Without governmentwide coordination and accountability, agencies can still elect to go their own way, perhaps spending money on facilities and equipment already available elsewhere.

Recommendations

To help ensure the cost-effectiveness of future federal or federally financed DGPS applications, we recommend that the Office of Management and Budget take the lead in establishing a more coordinated governmentwide approach to managing DGPS. Such an approach could take the form of establishing a coordinative mechanism for all civil DGPS applications and giving it the authority to establish policies, procedures, and standards needed to facilitate joint development and use of DGPS technology. It could also take the form of requiring that any federal agencies proposals to (1) add DGPS base stations in fiscal years 1998 and beyond or (2) participate in federal financing of base stations to be acquired by state or local government units demonstrate to the Office of Management and Budget that acquiring the base stations and related equipment would be more cost-effective than using base stations owned or operated by other federal agencies.⁷

Agency Comments

As requested, we did not obtain official agency comments on a draft of this report. However, we did discuss the results of our review with officials of DOD, DOT, the Corps of Engineers, BLM, Forest Service, the U.S. Geological Survey, NOAA, EPA, OMB, and the U.S. Industry Council for Global Positioning Systems. Generally, DOT officials (such as the Acting Director, Radionavigation and Positioning Staff, Office of the Assistant Secretary for Transportation Policy) agreed with our recommendations concerning the need for a stronger mechanism to coordinate federal DGPS activities. They believed the structure proposed by the DOD-DOT task force could bring

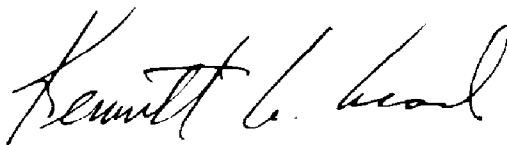
⁷This requirement should not apply to DGPSS undergoing research and development or operational testing.

about better coordination but acknowledged that the proposed structure lacked authority over non-DOT agencies. Officials at OMB with oversight responsibility over transportation and natural resource agencies agreed action by OMB was needed to develop a stronger coordinative mechanism for federal DGPS activities. They indicated they were considering various options for how best to coordinate these activities, including our recommendation regarding future justification of DGPS budget requests. Officials of all other agencies reviewed—including the Chair, Federal Geodetic Control Subcommittee, Federal Geographic Data Committee—agreed with our conclusions and recommendations. Where appropriate, we have incorporated changes suggested by agency officials to clarify the report.

We conducted our review between August 1993 and August 1994 and performed the work in accordance with generally accepted government auditing standards. See app. II for a discussion of our scope and methodology.

As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after the date of this letter. At that time, we will send copies of this report to the heads of pertinent federal departments and agencies, industry representatives, and other interested parties. Copies will be available to others upon request.

If you or your staff have any questions about our review, I can be reached at (202) 512-2834. Major contributors are listed in app. III.



Kenneth M. Mead
Director, Transportation and
Telecommunication Issues

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Abbreviations

BLM	Bureau of Land Management
DGPS	Differential Global Positioning System
DOD	Department of Defense
DOT	Department of Transportation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
OMB	Office of Management and Budget
RINEX	Receiver Independent Exchange

Federal Agency DGPS Applications

Nine of the 13 federal agencies contacted were designing, implementing, or operating differential global positioning systems (DGPS) for various applications.¹ These applications included navigation, surveying/mapping, and other uses. Table I.1 provides a brief description of these activities.

¹The remaining four federal agencies did not own or operate DGPS base stations. These agencies were the Federal Transit Administration, the Federal Highway Administration, the Federal Railroad Administration, and the Department of Defense (DOD). However, the Federal Transit Administration and the Federal Highway Administration provide funding to state and local authorities, and this funding may support DGPS base stations at the state or local levels. A DOD official said that DOD does not use DGPS technology for military operations.

**Appendix I
Federal Agency DGPS Applications**

Table I.1 Federal Agency DGPS Applications

Federal agency	Number of DGPS base stations ^a		Principal DGPS application
	Actual as of 3/31/94	Planned ^b	
Forest Service	26	0	Resource management activities, such as mapping and surveying property corners, roads, trails, and water resources
Federal Aviation Administration	0	734	Aviation navigation, including enroute flights, terminal activity, and precision and nonprecision landing approaches
Environmental Protection Agency	4	1	Environmental monitoring, such as surveying and mapping landfills, wells, outfalls, and other facilities
U.S. Coast Guard	8	55	Marine navigation, including harbor and harbor approaches
Bureau of Land Management	16	11	Land management activities, including surveying and mapping property corners, gathering geographic data, and suppressing fires
National Oceanic and Atmospheric Administration	3	2	Surveying and mapping U.S. continental waters and gathering spatial data for geographic applications
Army Corps of Engineers	17	19	Dredging and buoy placement activities
U.S. Geological Survey	2	0	Earthquake fault movement detection
St. Lawrence Seaway Development Corporation	1	0	Buoy placement

^aIncludes only permanent DGPS base stations—that is, equipment and facilities that are in one place for 6 months or longer.

^bFiscal years 1994-96.

Among the 13 agencies contacted, the Federal Aviation Administration (FAA) and the Coast Guard are undertaking the largest DGPS networks.

Their networks will not only provide DGPS coverage for air and marine applications but also will be used by other agencies for surveying, mapping, and other applications. The FAA and Coast Guard DGPS networks are briefly described below.

FAA DGPS Network

FAA's planned system consists of two main parts—a wide-area network covering the entire country and a local-area DGPS to provide more accurate positioning information needed for landings at major airports. By 1998, FAA plans to establish its Wide-Area Augmentation System. The system will augment the integrity, availability and accuracy of the basic global positioning system signals so the augmented system can be used as the primary means of navigation for all phases of flight except those requiring higher accuracies (i.e., Category II/III precision approaches). FAA estimates that equipment needed for the wide-area system will cost about \$500 million.

The wide-area system will contain up to 33 base stations. Each base station will be composed of a primary unit and two backups to provide a high degree of reliability through redundancy. Base stations will collect positioning data from global positioning system satellites and communicate these data to up to six master control stations. In turn, the master control station will transmit the DGPS correctional information to up to nine geostationary satellites for broadcasting. According to FAA officials, this system will provide horizontal accuracies of about 3 meters and vertical accuracies of about 5 meters throughout the United States. To provide continuous navigational integrity, the system is designed to be available 99.999 percent of the time and provide notification of a bad signal within 6 seconds. Each base station will also be able to provide DGPS data to other federal users for post-processing applications such as surveying and mapping.

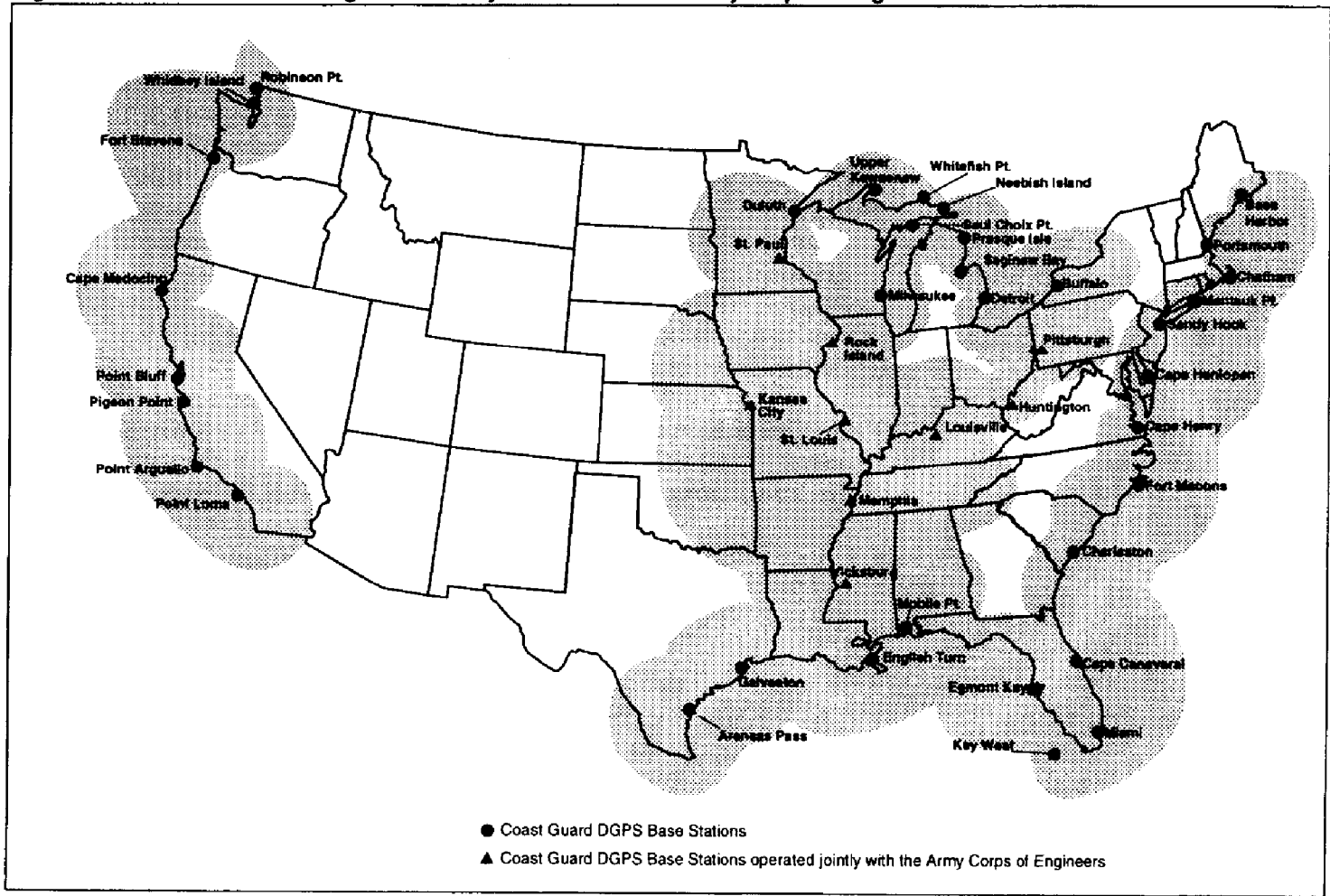
For its local-area system, FAA also plans to have up to 701² DGPS base stations to provide greater positioning accuracies for Category I, II and III precision landings at airports. An FAA official estimated that it would cost about \$1 million for each of these local area systems, but the cost of such equipment would be financed by the local airport authority.

²According to an FAA official, the total number of base stations for the local-area DGPS at major airports could be considerably less if national security policy permits the Wide Area Augmentation System to generate navigation signals accurate enough to support Category I precision approaches.

Coast Guard DGPS Network

To provide electronic aids to navigation for maritime commerce in the United States, the Coast Guard plans to install DGPS base stations at 49 sites along the coastal United States, the Great Lakes, Puerto Rico, Alaska, and Hawaii. Fourteen additional DGPS sites are planned for the Mississippi and Ohio River valleys. These additional base stations will be jointly operated with the Army Corps of Engineers. (See fig. II.I for DGPS coverage areas in the continental United States). The Coast Guard will also explore the possibility of providing additional DGPS coverage for all inland waterways.

Figure II.1: Location and Coverage Provided by Coast Guard and Army Corps of Engineer DGPS Base Stations



Note: This map is based on Coast Guard data as of July 1994. Not included is DGPS coverage for Alaska, Hawaii, and Puerto Rico.

The Coast Guard's DGPS network was designed to provide accuracies of 8 to 20 meters for harbor approach and harbor navigation. However, subsequent refinements have produced accuracies to 3 meters in real-time, which can be used for river and harbor hydrographic surveying. Other Coast Guard uses of DGPS include positioning buoys and aids to navigation and monitoring and controlling port traffic as part of the Coast Guard's Vessel Traffic Services.

Equipment at each Coast Guard DGPS site will include a dual frequency receiver to record positioning information from global positioning system satellites. In turn, the base stations will broadcast corrected signals via radiobeacons to marine users. DGPS data will also be stored on computers and made available to federal agencies or the public for such post-processing applications as mapping and surveying.³ A second DGPS base station will be located at each site and will monitor system accuracy and integrity via continuous integrity checks. A communication link between all stations will allow remote monitoring by one West Coast and one East Coast regional DGPS control station, which will be monitored 24 hours a day. The control stations will also automatically record and archive all DGPS data as well as assess the system's ability to meet operational performance requirements, detect system anomalies, and provide a record of operational conditions at all stations. The control stations will also allow control of the DGPS system by the national command authority in the event of a national emergency.

Coast Guard DGPS equipment costs are estimated at \$17.8 million. Operations and maintenance costs are estimated at \$5 million annually. The DGPS network will have an expected useful life of 25 years.

³In a May 1994 memorandum of agreement, the Coast Guard and the Coast and Geodetic Survey, National Oceanic and Atmospheric Administration, Department of Commerce agreed to cooperate in making DGPS data available to federal and other DGPS users in formats suitable for surveying and mapping. Under the agreement, the National Geodetic Survey would acquire and operate whatever computer and communication equipment is needed to provide public access to the DGPS data.

Scope and Methodology

We reviewed both existing and planned DGPS equipment, facilities, and operating policies and procedures with 13 federal agencies. This included six agencies within the Department of Transportation: the FAA, Federal Highway Administration, Federal Railroad Administration, Federal Transit Administration, U.S. Coast Guard, and St. Lawrence Seaway Development Corporation. Other agencies reviewed included the Bureau of Land Management, U.S. Forest Service, U.S. Geological Survey, National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corps of Engineers, and Department of Defense. We selected these 13 agencies to obtain diversity in the size and type of existing or planned navigation or surveying/mapping DGPS applications.

At each agency we interviewed officials responsible for designing and implementing DGPS applications and obtained any documents, studies, or reports related to existing or planned DGPS equipment, facilities, or applications. To identify existing and planned DGPS equipment and facilities at field office locations, we contacted agency personnel in selected regional offices of the Bureau of Land Management, Environmental Protection Agency, Forest Service, U.S. Geological Survey, and Army Corps of Engineers.

To determine efforts to coordinate federal DGPS applications, we interviewed federal officials responsible for directing the activities of the U.S. Coast Guard's Global Positioning System Information Center and the Civil Global Positioning System Service Interface Committee. We discussed DGPS coordination with the Executive Secretariat of the Federal Geographic Data Committee; the Chair of the Federal Geodetic Control Subcommittee; and the Chair of the Fixed Reference Station Working Group, Geodetic Control Subcommittee, Federal Geographic Data Committee. We also discussed federal agency DGPS activities with the Executive Secretary and the Executive Director for Policy of the U.S. Global Positioning System Industry Council, and we met with Department of Transportation representatives to the joint Department of Defense-Department of Transportation Task Force. We also attended the Institute of Navigation's Satellite Division GPS-93 Conference and the 22nd meeting of the Coast Guard Global Positioning System Civil Interface Committee, both held in Salt Lake City, Utah, in September 1993.

Finally, on the basis of our work at the above locations, we developed a list of DGPS experts with whom we discussed federal agency DGPS activities and additional steps that may be needed to enhance joint development or sharing of federal DGPS facilities. We selected these experts on the basis of

Appendix II
Scope and Methodology

their knowledge, experience, and familiarity with existing and planned federal agency DGPS systems and applications.

**Appendix II
Scope and Methodology**

Table II.1: List of DGPS Experts Contacted

Agency/organization	Name/title	DGPS expertise
Environmental Protection Agency	Brenda Groskinsky, Environmental Scientist	Responsible for research and development for DGPS environmental monitoring applications
Headquarters, U.S. Army Corps of Engineers	William A. Bergen, Civil Engineer	Responsible for coordinating Corps' surveying and mapping activities
U.S. Army Corp of Engineers, Topographic Engineering Center	Sally Frodge, Geodesist	Conducting a study on the feasibility of a national DGPS network
Trimble Navigation, Ltd.	Dr. Peter Loomis, Staff Scientist	Involved in DGPS research for 9 years
National Oceanic and Atmospheric Administration	William Strange, Chief Geodesist	Chairman, Fixed Reference Station Working Group, Federal Geodetic Control Subcommittee
FAA Mitre Corporation	Robert Loh, Wide-Area DGPS Program Manager	Involved with aviation GPS and DGPS research for more than 11 years
FAA	Joseph Dorfier, Satellite Program Manager	Many years of experience with aviation engineering and research
U.S. Coast Guard	Joseph W. Spalding, Project Manager, Research and Development Center	Involved in GPS research for 8 years
U.S. Coast Guard	Cmdr. Doug Alsip, Chief, Radionavigation and Development Branch	Project manager for the Coast Guard's DGPS network
U.S. Geological Survey	Larry Hothem, GPS Research and Applications Manager	Responsible for implementing GPS technology into agency earth science programs
U.S. Global Positioning System Industry Council	Mike Swiek, Executive Secretary Ann Ciganer, Executive Director, Policy and Government Affairs Liaison, Trimble Navigation	Since 1991, the U.S. Global Positioning System Industry Council has been active in addressing the regulatory, political, and technical issues facing the global positioning system industry.
U.S. Forest Service	Anthony Jasumback, Global Positioning System Program Leader, Missoula Technology and Development Center	Since 1988, has been responsible for all Forest Service DGPS test and evaluation activities

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