
GPS HISTORY, CHRONOLOGY, AND BUDGETS

This appendix provides an overview of the programmatic and institutional evolution of the Global Positioning System (GPS), including a history of its growing use in the military and civilian world, a chronology of important events in its development, and a summary of its costs to the government.

THE HISTORY OF GPS

Throughout time people have developed a variety of ways to figure out their position on earth and to navigate from one place to another. Early mariners relied on angular measurements to celestial bodies like the sun and stars to calculate their location. The 1920s witnessed the introduction of a more advanced technique—radionavigation—based at first on radios that allowed navigators to locate the direction of shore-based transmitters when in range.¹ Later, the development of artificial satellites made possible the transmission of more-precise, line-of-sight radionavigation signals and sparked a new era in navigation technology. Satellites were first used in position-finding in a simple but reliable two-dimensional Navy system called Transit. This laid the groundwork for a system that would later revolutionize navigation forever—the Global Positioning System.

The Military Evolution of GPS

The Global Positioning System is a 24-satellite constellation that can tell you where you are in three dimensions. GPS navigation and position determination is based on measuring the distance from the user position to the precise locations of the GPS satellites as they orbit. By measuring the distance to four GPS satellites, it is possible to establish three coordinates of a user's position

¹The marine radionavigation aid LORAN (Long Range Aid to Navigation) was important to the development of GPS because it was the first system to employ time difference of arrival of radio signals in a navigation system, a technique later extended to the NAVSTAR satellite navigation system.

(latitude, longitude, and altitude) as well as GPS time. (See Appendix A for a technical explanation of how GPS works.)

Originally developed by the Department of Defense (DoD) to meet military requirements, GPS was quickly adopted by the civilian world even before the system was operational. This section describes the evolution of GPS, from its conceptualization to the present day, tracing its military development and its emergence in the civilian world.

The Forerunners of GPS. DoD's primary purposes in developing GPS were to use it in precision weapon delivery and to provide a capability that would reverse the proliferation of navigation systems in the military.² Beginning in the early 1960s, the U.S. Department of Defense began pursuing the idea of developing a global, all-weather, continuously available, highly accurate positioning and navigation system that could address the needs of a broad spectrum of users and at the same time save the DoD money by limiting the proliferation of specialized equipment that supported only particular mission requirements. As a result, the U.S. Navy and Air Force began studying the concept of using radio signals transmitted from satellites for positioning and navigation purposes. These studies developed concepts and experimental satellite programs, which became the building blocks for the Global Positioning System.

The Navy sponsored two programs which were predecessors to GPS: Transit and Timation. Transit was the first operational satellite-based navigation system.³ Developed by the Johns Hopkins Applied Physics Laboratory under Dr. Richard Kirschner in the 1960s, Transit consists of 7 low-altitude polar-orbiting satellites that broadcast very stable radio signals; several ground-based monitor stations to track the satellites; and facilities to update satellite orbital parameters. Transit users determine their position on earth by measuring the Doppler shift of signals transmitted by the satellites.

Originally designed to meet the Navy's requirement for locating ballistic missile submarines and other ships at the ocean's surface, Transit was made available to civilian users in 1967. It was quickly adopted by a large number of commercial marine navigators and owners of small pleasure craft and is still operated by the Navy today.⁴ Although it has proved its utility for most ship navigation,

²Bradford W. Parkinson, "GPS Eyewitness: The Early Years," *GPS World*, September 1994, p. 42.

³The concept for Transit evolved from observations of the Russian satellite Sputnik in 1957. Researchers at the Applied Physics Laboratory (APL) discovered that measurements of the Doppler shift as the satellite passed by were adequate to determine the entire satellite orbit. Dr. Frank T. McClure of APL noted that conversely, if the satellite orbit were known, position on the earth could be determined using these same Doppler measurements.

⁴The Navy plans to terminate operation of the system by the end of 1996 according to the 1994 Federal Radionavigation Plan (Draft).

the system has a number of drawbacks. It is slow, requiring a long observation time, provides only two-dimensional positioning capability, has limited coverage due to the intermittent access/availability of its signals (with periods of unavailability measured in hours), and requires users to correct for their velocities—all of which make Transit impractical for use on aircraft or other rapidly moving platforms. Nonetheless, Transit was important to GPS because it resulted in a number of technologies⁵ that were extremely useful to GPS and demonstrated that a space system could offer excellent reliability.

Timation, a second forerunner of GPS, was a space-based navigation system technology program the Navy had worked on since 1964.⁶ This program incorporated two experimental satellites that were used to advance the development of high-stability clocks, time-transfer, and two-dimensional navigation. The first Timation satellite launched in 1967 carried very stable quartz-crystal oscillators; later models orbited the first atomic frequency standards (rubidium and cesium). The atomic clocks had better frequency stability than earlier clocks, which greatly improved the prediction of satellite orbits (ephemerides) and would eventually extend the time required between control segment updates to GPS satellites. This pioneering work on space-qualified time standards was an important contribution to GPS.⁷ In fact, the last two Timation satellites were used as prototype GPS satellites.

In the meantime, the Air Force was working on a similar technology program that resulted in a design concept called System 621B; it provided three-dimensional (latitude, longitude, and altitude) navigation with continuous service.⁸ By 1972, the system had already demonstrated the operation of a new type of satellite ranging signal based on pseudorandom noise (PRN).⁹ To verify the PRN technique, the Air Force ran a series of aircraft tests at White Sands Proving Ground in New Mexico using ground- and balloon-carried transmitters to simulate satellites. The technique pinpointed the positions of aircraft to within a hundredth of a mile.

⁵The satellite prediction algorithms developed for Transit were a significant contribution to GPS.

⁶Timation was developed by the Naval Research Laboratory (NRL) under the direction of Roger Easton.

⁷Parkinson, p. 34.

⁸The studies that led to System 621B originated at the Aerospace Corporation in 1963. Aerospace had begun looking at potential applications of space capabilities to meet critical military needs, one of which was the need for precise positioning of aircraft. In October 1963, the Air Force formally requested that Aerospace continue these studies, which later evolved into System 621B.

⁹The PRN technique had distinct advantages over other techniques, among them the ability to reject noise, which implies a strong ability to reject most forms of jamming or deliberate interference. With this technique, all satellites could transmit on the same frequency without interference. Also, a communication channel could be added which allowed the user to receive ephemeris (satellite location) and clock information.

At that time, the Air Force concept envisioned a global system consisting of 16 satellites in geosynchronous orbits whose ground tracks formed four oval-shaped clusters extending 30 degrees north and south of the equator. This particular geometry allowed for the gradual evolution of the system because it required only four satellites to demonstrate its operation capabilities. That is, one cluster could provide 24-hour coverage of a particular geographic region (for example, North and South America).

However, no real progress was made toward full-scale development of System 621B until 1973. Part of the reason for this was that the Air Force work had stimulated additional work on satellite navigation, giving rise to a number of competing initiatives from the other services. By the late 1960s, the U.S. Navy, Air Force, and Army were each working independently on radionavigation systems that would provide all-weather, 24-hour coverage and accuracies that would enhance the military capabilities of their respective forces.¹⁰ The APL had made technical improvements to Transit and wanted to upgrade the system, while the Naval Research Laboratory was pushing an expanded Timation system and the Army had proposed using its own system, SECOR (Sequential Correlation of Range). To coordinate the effort of the various satellite navigation groups, DoD established a joint tri-service steering committee in 1968 called the NAVSEG (Navigation Satellite Executive Group). The NAVSEG spent the next several years deciding what the specifics of a satellite navigation system should be—how many satellites, at what altitude, signal codes, and modulation techniques—and what they would cost.

Finally, in April 1973, the Deputy Secretary of Defense designated the Air Force as the lead agency to consolidate the various satellite navigation concepts into a single comprehensive DoD system to be known as the Defense Navigation Satellite System (DNSS). The new system was to be developed by a Joint Program Office (JPO) located at the Air Force's Space and Missile Organization, with participation by all military services. Colonel Brad Parkinson, program director of the JPO, was directed to negotiate between the services to develop a DNSS concept that embraced the views and needs of all services.

By September 1973, a compromise system was evolving which combined the best features of earlier Navy and Air Force programs. The signal structure and frequencies were taken from the Air Force's 621B. Satellite orbits were based on those proposed for the Navy's Timation system, but higher in altitude, giving twelve-hour instead of eight-hour periods. While both systems had proposed the use of atomic clocks in satellites, only the Navy had tested this idea. The

¹⁰Ivan A. Getting, "The Global Positioning System," *IEEE Spectrum*, Vol. 30, No. 12, December 1993, pp. 36-47.

system concept that emerged is what is known today as the NAVSTAR Global Positioning System. In December 1973, DoD granted the JPO approval to proceed with the first phase of a three-phase development of the NAVSTAR GPS.¹¹

Testing the GPS Idea (1974–1979). The first phase of the GPS program was intended to confirm the concept of a space-based navigation system, demonstrate its potential for operational utility, and establish the preferred design.¹² The original program was funded at about \$100 million and was supposed to cover four satellites, the launch vehicles, three types of user equipment, a satellite control facility, and an extensive test program.¹³

The very first NAVSTAR satellites were actually two refurbished Timation satellites built by the NRL. Known as Navigation Technology Satellite (NTS) numbers 1 and 2, they carried the first atomic clocks ever launched into space. Although these experimental satellites functioned for only short periods following their launches in 1974 and 1977, they proved the concept of time-based ranging using spread-spectrum radio signals and precise time derived from orbiting atomic clocks.

Soon after, the first developmental GPS satellites, known as Block Is, were launched and tested. This series of satellites supported most of the system's testing program. Between 1978 and 1985, a total of eleven Block I satellites built by Rockwell International were launched on the Atlas-F booster; one satellite was lost due to a launch failure. Others eventually failed due to deterioration of their atomic clocks or failures of their attitude control system. However, many of the Block I satellites continued to operate much longer than their design life of three years—in several cases more than 10 years longer.

Even before the first Block Is were launched, the military had begun planning a dual role for the GPS satellites. In addition to carrying the navigation and timing payload, GPS satellites would carry nuclear detonation (NUDET) sensors designed to detect nuclear weapon explosions, assess nuclear attack, and help in evaluating strike damage.¹⁴ The system would also contribute to monitoring

¹¹An earlier attempt to gain approval for the system was made in August 1973, but failed because the program presented to DoD at that time was not representative of a joint program, but rather a repackaged version of the Air Force's System 621B.

¹²The second phase of GPS was devoted to full-scale engineering development, and the third to production and deployment of the GPS segments.

¹³This funding was apparently just enough to cover the satellites but not enough for the other elements of the first phase of the program. Jeffrey A. Drezner and Giles K. Smith, *An Analysis of Weapon System Acquisition Schedules*, RAND, R-3937-ACQ, December 1990, p. 181.

¹⁴"GPS to Test Nuclear Detonation Sensor," *Aviation Week & Space Technology*, August 27, 1979, p. 51.

compliance with the nuclear test ban treaty. The first GPS satellite to carry a nuclear explosion detection sensor was the sixth Block I satellite, launched on April 26, 1980.¹⁵ The use of satellites for detecting nuclear explosions dates back to the 1963 Limited Test Ban Treaty between the United States and the Soviet Union, which prohibited nuclear testing in the atmosphere, underwater, and in space. To monitor the ban, the U.S. Air Force and the Atomic Energy Commission (predecessor to the Department of Energy) jointly developed a series of nuclear detection satellites known as Vela. Since then, nuclear detection sensors have been orbited on a number of other DoD satellites, including the NAVSTAR satellites, in an effort to increase the number of detection satellites in space and to improve the existing detection network.¹⁶ The sensors flown on GPS satellites are similar to those initially used on the Vela satellites. The satellites which currently make up the GPS constellation all have the capability to detect nuclear detonations and are presently an important component in the United States' capability to monitor compliance with the Nuclear Non-Proliferation Treaty of 1968.¹⁷ According to DoD plans, future GPS satellites will continue to serve the nuclear detection mission.

Testing of GPS user equipment began in March 1977 before any satellites were in place. A system of solar-powered ground transmitters was set up on the desert floor at the Army's Yuma Proving Ground in Arizona to simulate GPS satellites. These transmitters, known as pseudolites (taken from the term pseudosatellites), broadcast a signal that has a structure similar to that of a GPS satellite.¹⁸ Although the signals were coming from the ground rather than from space, they provided a geometry that approximated that of the satellites. By the time four Block I satellites were in orbit (1978), the JPO was running tests on several types of user equipment carried on aircraft, helicopter, ships, trucks, jeeps, and even by men using 25-pound backpacks.

The final segment of GPS—a prototype ground control system—was located at Vandenberg AFB, CA, during this period. With all the basic components of the

¹⁵The sensor carried on this satellite was called the Integrated Operational Nuclear Detonation Detection System (IONDS); later GPS satellites were fitted with a new sensor known as Nuclear Detonation Detection System (NDS).

¹⁶Other DoD satellites that have carried nuclear detection sensors include the Defense Support Program satellites used for early warning of missile launch and the Defense Meteorological Satellite Program. For further information, see Bhupendra Jasani, *Verification of a Comprehensive Test Ban Treaty from Space: A Preliminary Study*, United Nations, New York, Research Paper No. 32, 1994.

¹⁷The GPS Nuclear Detonation Detection System is managed as a joint program between the U.S. Air Force and the Department of Energy (DoE). The Air Force provides the "platform"—the GPS satellites—and operates the system; DoE provides the sensors through its national laboratories, Sandia and Los Alamos.

¹⁸The pseudolite concept has since become an important technique for improving accuracy and integrity for civil landing of aircraft.

system in place, the JPO was given the go-ahead to proceed with full-scale development of GPS in August 1979.

GPS Grows Up (1980–1989). Efforts to expand the fledgling GPS program suffered some growing pains during the development phase.

The first setback was brought on by a 1979 decision by the Office of the Secretary of Defense (OSD) to cut \$500 million (approximately 30 percent) from the budget over the period FY81–FY86.¹⁹ As a result, the GPS program was restructured and the scope of the program reduced. The final satellite constellation was cut from 24 to 18 satellites (plus three satellites serving as on-orbit spares); Block II development satellites were dropped; and the design was scaled down in terms of weight, power, and nuclear and laser hardening.²⁰ Plans for attainment of an early limited two-dimensional capability in 1981 were also dropped.

Funding for GPS was somewhat unstable during the early stages of the program even though it received support from many elements of the services. Because GPS is a support system and not a standard weapon system with a clear mission and a history of well-defined operational concepts, early understanding of the value of the system was less straightforward than with tanks or aircraft. This increased the need to sell the program, particularly to potential users. The JPO addressed this problem, especially during Phase I, by emphasizing one of the more tangible capabilities of the system: increased bombing accuracy. The fact that GPS was a joint program also increased the need to sell the program to multiple services. No one service was anxious to bear the entire financial load for a support system that was to be used by all services. As a result, GPS had service support difficulties. For example, the program was zeroed out in 1980 through 1982, but was reinstated by OSD.²¹ It appears that OSD support contributed to the survival of the program.

GPS suffered another setback as a result of the Space Shuttle Challenger accident in 1986. As the only planned launch vehicle for GPS satellites at that time, the loss of the shuttle caused a 24-month delay in the scheduled launch of the second generation of GPS satellites, the Block IIs. Originally, the JPO planned to launch the first 12 satellites (Phase I) on refurbished Atlas F boosters and to use the McDonnell-Douglas Delta for the next series of launches (Phase II). Around 1979, the JPO had responded to DoD decisions which designated the Space Shuttle as the principal launch vehicle for Air Force missions. Although the

¹⁹Drezner, p. 184.

²⁰The GPS constellation was later restored in 1988 to its original configuration of 24 satellites, including three spares, because the performance by 18 satellites was found inadequate.

²¹Drezner, p. 188.

Block IIs were built to be compatible with shuttle deployment, the JPO decided to switch back to the Delta II as the GPS launch vehicle following the Challenger disaster.

The first Block II satellite was eventually launched in February 1989 from Cape Canaveral AFS, and became operational for global use in April 1989. Since then, there have been 23 more Block II satellite launches. Like the Block I satellites, the Block IIs were produced by Rockwell International. The Block II satellites differ from the Block Is in shape and weight and incorporate design differences that affect security and integrity.²² Significant Block II satellite enhancements include:

- Radiation-hardened electronics to improve reliability and survivability
- Full selective availability (SA) and anti-spoofing (AS) capabilities to provide system security
- Automatic detection of certain error conditions and switching to nonstandard code transmission or default navigation message data to protect users from tracking a faulty satellite and to maximize system integrity.

Block II satellites launched after 1989 have the additional capability of operating for up to 180 days without contact from the control segment. They are called Block IIAs. This represents a significant improvement over the earlier Block I and II satellites, which required updating from the control segment after only 3.5 days.

Further progress was made on the control and user equipment segments of GPS during this period. As part of the transition to an operational and sustainable system, the control segment was transferred to a new master control station located at Falcon AFB, CO. System testing was completed, and successful interoperability was demonstrated between the ground control stations, the satellites, and the “user” navigation equipment. Rockwell-Collins was chosen as the contractor for the production GPS user equipment. By the turn of the century, an estimated 17,000 U.S. military aircraft will be equipped with GPS, and 60,000 portable receivers will be in use by U.S. ground forces and on military vehicles.²³

²²*Security* refers to features built into GPS that can deny accurate service to unauthorized users, prevent spoofing, and reduce receiver susceptibility to jamming. These security measures, designed only with the military in mind, can cause difficulties for unauthorized users, i.e., anyone without a specific military need and/or mission. *Integrity* refers to the ability of the system to provide timely warnings to users when the system should not be used for navigation.

²³The Aerospace Corporation, *The Global Positioning System: A Record of Achievement*, 1994.

Recent Military Use of GPS (1990–present). The 1990–1991 crisis in the Persian Gulf, the first major test²⁴ of GPS in a combat situation, proved beyond a doubt the importance and utility of the NAVSTAR. Some say that GPS revolutionized combat operations on the ground and in the air during Operation Desert Storm and was—as one Allied commander noted—one of two particular pieces of equipment that were potential war winners (the other was night-vision devices).²⁵

Among the many uses of GPS in Operation Desert Storm, navigation proved to be a crucial technique for desert warfare.²⁶ GPS satellites enabled coalition forces to navigate, maneuver, and fire with unprecedented accuracy in the vast desert terrain almost 24 hours a day²⁷ despite difficult conditions—frequent sandstorms, few paved roads, no vegetative cover, and few natural landmarks. Although on average, each U.S. Army maneuver company (e.g., tank, mechanized infantry, or armored cavalry) had at least one GPS receiver, the demand for receivers was so great that more than 10,000 commercial units were hastily ordered during the crisis so that more coalition forces could benefit from the system.

Other operations made possible or greatly enhanced by GPS include precision-bombing, artillery fire support, the precise positioning of maneuvering troop formations, and certain special forces operations such as combat search-and-rescue missions. As well as being carried by foot soldiers, GPS receivers were attached, in some cases with tape, to vehicles and helicopter instrument panels and were also used in F-16 fighters, KC-135 tankers, and B-52 bombers.

Since the Persian Gulf War, the United States has employed GPS in several peacekeeping and military operations. During Operation Restore Hope in 1993, GPS was used to air drop food and supplies to remote areas of Somalia because of lack of accurate maps and ground-based navigation facilities. U.S. forces entering Haiti in 1994 also relied on GPS. During the present Balkan crisis, GPS has assisted in delivery of aid to the Bosnians by guiding U.S. Air Force trans-

²⁴GPS played only a minor role in military operations of the 1980s. For example, the U.S. Navy used GPS to determine the position of minefields in the Persian Gulf in 1987–1988, and the U.S. Air Force used GPS during the intervention in Panama in December 1989 (Operation Just Cause) to overcome inaccuracies in maps that showed key bridges in the wrong position.

²⁵Michael Russel Rip and David P. Lusch, “The Precision Revolution: The Navstar Global Positioning System in the Second Gulf War,” *Intelligence and National Security*, Vol. 9, No. 2, April 1994, pp. 167–241.

²⁶Rip, p. 171.

²⁷Sixteen GPS satellites were active during the crisis. Block II satellites launched during Operation Desert Storm were adjusted to place them in an optimal position to provide maximum GPS coverage over the region.

port planes at night to their drop zones where food and medicine is then parachuted close to towns and villages.

Current Status of NAVSTAR GPS. The launch of the 24th Block II²⁸ satellite in March 1994 completed the GPS constellation. The NAVSTAR system currently consists of 25 satellites, including one Block I satellite.²⁹ Initial Operational Capability (IOC) was formally declared December 8, 1993, in a joint announcement by the DoD and the Department of Transportation (DoT).³⁰ The IOC notification means that the NAVSTAR GPS is capable of sustaining the Standard Positioning Service (SPS), the 100-meter positioning accuracy available to civilian users of the system on a continuous, worldwide basis.³¹ Unlike IOC for other DoD systems, IOC for GPS has purely civil connotations.

In 1995, the U.S. Air Force Space Command formally declared the GPS met the requirements for Full Operational Capability (FOC),³² meaning that the constellation of 24 operational (Block II/IIA) satellites now in orbit has successfully completed testing for military functionality. While the FOC declaration is significant to DoD because it defines a system as being able to provide full and supportable military capability, it does not have any significant impact on civil users.

An additional 21 satellites called Block IIRs are being developed by Martin Marietta (formerly General Electric Astro Space division) as replacements for the current GPS satellites.³³ The Block IIR satellites will provide enhanced performance over the previous generation of GPS satellites, including the capability to autonomously navigate (AUTONAV) themselves and generate their own navigation message data. This means that if the control segment cannot contact the Block IIR satellites, the AUTONAV capabilities will enable these

²⁸A total of 28 Block II satellites were built by Rockwell. There are four remaining Block II satellites in reserve, two of which are scheduled to be launched "on need" in 1995 and the other two during 1996. Glen Gibbons, "AF Says GPS Fully Operational," *GPS World Newsletter*, May 22, 1995, p. 5.

²⁹The sole Block I spacecraft was taken off-line in June 1995 after nearly 11 years of service, due to declining performance.

³⁰IOC requires a combination of at least 24 operating Block I and Block II satellites in orbit.

³¹Prior to IOC, GPS was considered a developmental system whose operation, including signal availability and accuracy, was subject to change at the discretion of DoD. Subsequent to IOC, any planned disruption of the SPS in peacetime will be preceded by a 48-hour advance notice to users through the Coast Guard GPS Information Center (GPSIC) and the FAA's Notice to Airmen (NOTAM) system. Unplanned system outages will be announced by the GPSIC and NOTAM systems as they become known.

³²U.S. Air Force Space Command Public Affairs Office, "Global Positioning System Fully Operational," news release, July 17, 1995.

³³The contract for the Block IIR satellites was awarded in June 1989.

satellites to maintain full system accuracy for at least 180 days.³⁴ The Block IIR satellites will be available for launch as necessary beginning in late 1996.

A follow-on set of replenishment satellites, known as Block IIFs, is planned to replace the Block IIR satellites at the end of their useful life. The Air Force intends to buy 33 Block IIF satellites³⁵ to sustain the quality of the GPS signal as a worldwide utility for the foreseeable future.³⁶ These satellites will have to meet even higher levels of performance than previous generations of GPS satellites, including a longer life cycle of 6.5 to 10 years. The IIF satellite will be launched on an Evolved Expandable Launch Vehicle (EELV).³⁷ The Air Force issued a draft request for proposals (RFP) on June 20, 1995, and plans to award a contract for the development and procurement of the Block IIF satellites in spring 1996.³⁸

The Evolution of GPS in the Civilian World

This section examines the U.S. government's public responses to the growing number of civil users, the role of government agencies and other private-sector agents in fostering commercial GPS markets, and present GPS governance and management. With the proliferation of civil government and private-sector users and the widening array of commercial GPS applications, the U.S. government is having to juggle a growing set of civilian demands on the system along with the military demands.³⁹ This has given rise to a number of issues discussed here and in Chapter Two.

The United States Opens GPS Up to Civilians. The first U.S. pronouncement regarding civil use of GPS came in 1983 following the downing of Korean

³⁴If the control segment lost contact with the Block I and Block II satellites, the satellites would continue transmitting the stored navigation message data previously uploaded by the control segment for 3.5 and 180 days, respectively. However, the system accuracy would degrade over time.

³⁵Originally, the Air Force planned to buy 51 satellites. However, concerns over the legal and political ramifications of issuing such a large contract caused the service to scale back its planned buy to 33 satellites. "House Appropriators Cut GPS Block IIF, Add \$100 Million For SBIRS," *Aerospace Daily*, Vol. 175, No. 17, July 27, 1995, pp. 129-130.

³⁶The JPO also plans to procure six follow-on satellites as eventual replacements for the Block IIF satellites.

³⁷EELV is a U.S. Air Force effort to develop by 2000 a new family of space boosters based on existing systems. The goal of this program is to lower the cost of launching medium and heavy U.S. government payloads into orbit. Warren Ferster, "Russian Rocket Engines Vie for Role in EELV Effort," *Space News*, May 8-14, 1995, p. 12.

³⁸The value of the IIF contract is estimated to be in excess of \$2 billion. Three teams are interested in bidding: Lockheed Martin, Loral Federal Systems, ITT; Rockwell International, Computer Sciences Corp., Rockwell Anaheim; and Hughes Space and Communications, National Systems & Research and Stanford Telecommunications and Space Applications. "Air Force Set To Release RFP on \$2 Billion GPS Block IIF Contract," *CAI* via NewsPage, May 11, 1995.

³⁹Parkinson, p. 44. Civil GPS receivers currently outnumber military receivers by more than 10 to 1.

Airlines Flight 007 after it strayed over territory belonging to the Soviet Union. At this time, President Reagan announced that the Global Positioning System would be made available for international civil use once the system became operational. In 1987 DoD formally requested the Department of Transportation to establish and provide an office to respond to civil users' needs and to work closely with the DoD to ensure proper implementation of GPS for civil use. Two years later, the U.S. Coast Guard became the lead agency for this project.

The Reagan announcement was followed by a U.S. offer to make available the Standard Positioning Service of GPS, which was announced at the International Civil Aviation Organization's (ICAO) Tenth Air Navigation Conference, September 5, 1991. The Federal Aviation Administration's (FAA) Administrator, James Busey, promised that GPS would be available free of charge to the international community beginning in 1993 on a continuous, worldwide basis for at least 10 years. This offer was extended the following year at the 29th ICAO Assembly, when the United States offered SPS to the world for the foreseeable future and pledged to provide at least six years notice prior to termination of GPS operations or elimination of the GPS SPS.

Both offers were formally reiterated in a 1994 letter from the FAA's chief, David Hinson, to ICAO, reaffirming the U.S. government's intention to provide GPS SPS free of charge for at least 10 years.⁴⁰ In 1995, President Clinton once again confirmed the government's commitment to provide GPS signals to international civil users in a statement that was released at an ICAO meeting in Montreal in March.⁴¹

The U.S. Government's Role in Fostering Commercial GPS Markets. The birth of one of the first GPS markets—surveying—was influenced by a 1984 decision by the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA)⁴² to publish the first draft standards in the Federal Register that allowed for the use of GPS data. This seal of approval of GPS data by a civil government agency helped jump start the expansion of the surveying market even while the GPS system was still in development.

By the mid-1980s, commercial GPS equipment aimed at the surveying profession appeared on the market even though only a small number of operating GPS satellites were in orbit. Surveying and time transfer were logical entry

⁴⁰David Hinson, FAA Administrator, letter to Dr. Assad Kotaite, President of the Council, International Civil Aviation Organization, October 14, 1994.

⁴¹Bill Clinton, President of the United States, letter to the International Civil Aviation Organization, March 16, 1995.

⁴²NOAA has historically chaired the Federal Geodetic Control Committee, which sets standards for mapping and geodesy.

points into the market because their applications could accept the limited availability of satellite signals.⁴³ Surveyors did not need to use their data in real time, but could make observations whenever sufficient satellite signals were available, day or night. GPS surveying offered greater productivity and cost savings over traditional survey methods. Tasks that normally required several weeks or months to finish could now be completed in a fraction of the time using GPS—at one-fifth to one-tenth of the cost of conventional surveying.⁴⁴ Satellite surveying also helped sustain the commercial market for GPS equipment after the Challenger disaster shut down operations and delayed satellite launches for several years.

The money generated by the survey market boom was also important to the overall development of GPS applications because it enabled U.S. manufacturers to invest in research and development (R&D) on GPS technology. The added R&D investment helped accelerate the development of GPS applications faster than would have been possible had the DoD been left to carry out this task on its own. In fact, surveyors were the first to employ some of the more advanced differential GPS techniques being used today, such as kinematic surveying and real-time carrier phase tracking. Now, ten years after the first standards were published, almost all geodetic standards are based on GPS data.

The growth in the GPS survey market opened the way for a number of GPS niche markets such as aviation. Even in these smaller markets, government agencies have contributed to their expansion. For example, the FAA issued performance standards for GPS receivers (Technical Standard Order C129) in 1992. This action allowed manufacturers to build GPS receivers as supplemental navigation aids for aircraft, thereby broadening the range of market opportunities for GPS suppliers. As evidence of this, Trimble, the first company to be awarded the GPS Technical Standard Order certification, signed an agreement with Honeywell in 1995 to cooperate in developing GPS products for the commercial, space, and military aviation markets. This alliance will allow both companies to tap into new GPS markets.

Government export controls have also affected GPS markets. Prior to 1991, most GPS user equipment shipped abroad required individual validated licenses to ensure compliance with various Department of Commerce (DoC) Bureau of Export Administration export control programs. On September 1, 1991, the DoC revised its export list of electronic equipment requiring licenses for shipment abroad. What the DoC essentially did was to make a clear delin-

⁴³Frank Kuznik, "You Are Here: GPS Satellites Can Tell You Where You Are—Within Inches," *Air & Space*, June/July 1992, pp. 34–40.

⁴⁴Cost estimates provided by the U.S. GPS Industry Council.

eation between military and civil GPS user equipment. Under the revised regulations, civilian GPS receivers, other satellite equipment, and telecommunications systems were freed of restrictions and were allowed to be shipped as “general destination items,” although military receivers, GPS null steerable antennas, encryption devices, and certain other components were still treated as “munitions” with strict export restrictions.⁴⁵ This liberalization of export controls helped speed up the U.S. industry’s entry into foreign markets. Today, export markets are important to U.S. GPS manufacturers, making up an average of 45 to 50 percent of overall sales.⁴⁶

The export controls issue also served as a catalyst for the U.S. commercial GPS industry to organize itself. Prior to the 1991 revision of export controls, U.S. manufacturers were concerned that foreign competitors were gaining an unfair advantage because of fewer restrictions. Fearing that the United States would lose control over an American-made space technology, a group of GPS manufacturers began working together to tackle export problems and in the process formed the U.S. GPS Industry Council (USGIC). The USGIC now has a permanent office in Washington, D.C., and has incorporated as a nonprofit entity. The council monitors and addresses emerging regulatory, political, and global issues affecting the GPS industry and serves as an information resource for key policymakers.

By the time the GPS constellation neared completion in the early 1990s, domestic manufacturers were well aware of the commercial potential of GPS. Ironically, it was the military, through its involvement in the Persian Gulf conflict, that gave the commercial GPS market its biggest boost. The success of GPS in Operation Desert Storm sparked a surge in a growing multi-million-dollar market that had barely existed just a few years prior to the war. Desert Storm provided the setting for showing off all the military uses of GPS—from helping soldiers navigate across a featureless desert to enabling artillery and bomber units to target the enemy with unprecedented accuracy.

When the war broke out, there were a limited number of military receivers in the DoD inventory. This led the DoD to purchase thousands of GPS civilian receivers and the National Command Authority (NCA)⁴⁷ to turn off selective

⁴⁵Prior to revision of export controls, approximately 50 to 60 percent of all exports by U.S. GPS manufacturers required validated export licenses in advance. Following changes in the export list, the percentage of GPS receivers and products shipped without a validated license rose to 80 percent.

⁴⁶United States GPS Industry Council (USGIC), “GPS: A Dual-Use Technology Success,” Washington, D.C., 1994, p. 3.

⁴⁷The NCA is the President or the Secretary of Defense, with the approval of the President. The term NCA is used to signify constitutional authority to direct the Armed Forces in their execution of military action.

availability (SA) so that the troops could get better accuracy using the civilian receivers. The Pentagon bought most of the GPS receivers used in the Persian Gulf from Trimble Navigation and Magellan Systems. These two companies became emergency suppliers, selling the Pentagon 10,000 and 3,000 receivers respectively.⁴⁸ Close to 90 percent of the GPS receivers used in the war were of the commercial sort.⁴⁹

In addition to precipitating a rise in demand for GPS commercial receivers, the war provided GPS technology and the suppliers of GPS receivers broad exposure. News coverage of the conflict served as free publicity for the two main wartime suppliers. Following the war, Trimble Navigation's sales to non-DoD customers went from a fraction of overall sales to a majority.⁵⁰ Desert Storm was also instrumental in helping manufacturers ramp up operations.⁵¹ However, the war was also disruptive because manufacturing lines were turned to support DoD demand, and commercial GPS marketing efforts were slowed for the duration of the war. Nevertheless, in peacetime, the U.S. commercial GPS manufacturers continue to produce new and cheaper receivers.

While GPS markets have benefited from government policies and initiatives, the development in commercial markets has also contributed to the national security mission of GPS. The demand by civilian commercial users of GPS for smaller, better, cheaper receivers has directly benefited systems designed specifically for military use. For example, the precision lightweight GPS receiver (PLGR) used by U.S. military forces and designated a "non-developmental item" was built at a low cost and delivered on time in large part due to technical benefits derived from research and development being conducted for civilian commercial applications.⁵²

GPS Management Today. The Global Positioning System management structure is currently undergoing a transition. Until recently, DoD was solely responsible for the management and operations of GPS as well as for policy formulation regarding the system and its uses. Although DoD and the Department of Transportation cooperated on those aspects of GPS policy affecting civil access to the system, much of the decision authority rested with DoD, and ultimately with the National Command Authority. However, now the civil govern-

⁴⁸Kuznik, p. 39.

⁴⁹Rip, p. 173.

⁵⁰Andrew Jenks, "Bursting into Bloom After Desert Storm," *Washington Technology*, October 8, 1992, p. 17.

⁵¹Jenks, p. 18.

⁵²USGIC, p. 1.

ment sector—primarily DoT—has been given a more active role in GPS management.

Many changes occurring are a result of recommendations made by a joint task force of the Departments of Defense and Transportation in 1993. The Joint DoD/DoT Task Force (JTF) was established after the Secretaries of Defense and Transportation agreed to examine the operational, technical, and institutional implications of increased civil use of GPS. The JTF was directed to (1) evaluate services derived from GPS signals; (2) evaluate the ability of GPS, as managed and operated by the DoD, to meet the needs of civil users; (3) assess the importance of GPS services to civil, commercial, and national security objectives; and (4) assess the long-term U.S. government sustainment of GPS as a national resource. The JTF recommendations, released in a report in December 1993,⁵³ point to seven core areas where GPS is not meeting civil user expectations or where alternate management strategies have been recommended. The GPS management structure was one of the core areas where the JTF saw room for improvement.⁵⁴ The JTF recommended that steps be taken to enhance civil participation in developing GPS policy and in managing the basic system and planned augmentations.⁵⁵ Thus the U.S. government is now involved in striking a balance between military and civil requirements and providing channels for both sectors to offer input to GPS management and policymaking.

The Domestic Military–Civil GPS Balance. The following overview of the current GPS management structure is intended to show how the United States balances the military and civilian roles domestically as well as in the international arena.

National Security. The Department of Defense is responsible for the day-to-day management and operation of GPS. Within DoD, the U.S. Air Force is in charge of carrying out these responsibilities. Research and development is managed by the GPS Joint Program Office (JPO), which is part of the Air Force Materiel Command in Los Angeles. Personnel from other military services, DoT, NATO, and other allied nations are also involved. Testing and evaluation are conducted jointly by the Air Force Operational Test and Evaluation Center and Air Force Space Command (AFSPACCOM), which also manages the operation and maintenance of the system.

⁵³Joint Department of Defense/Department of Transportation Task Force, *The Global Positioning System: Management and Operation of a Dual Use System, A Report to the Secretaries of Defense and Transportation*, Washington, D.C., December 1993.

⁵⁴The other core issues examined in the report are funding, accuracy, availability and integrity, regulation of GPS augmentations, international acceptance, and spoofing and jamming.

⁵⁵Joint Department of Defense/Department of Transportation Task Force, p. 20.

Funding to support the basic GPS is appropriated in the DoD budget. The Assistant Secretary of the Air Force for Acquisition has budgetary oversight for all funding for procurement and launch of the GPS satellites and for the control segment. The Department of Energy provides additional funding to procure Nuclear Detection Detonation System (NDS) payloads. Federal civil agencies are responsible for providing their own resources to modify or enhance the capabilities of GPS to meet unique civil requirements.⁵⁶ Each agency is responsible for procuring user equipment to meet its mission needs.

Responsibility for policy formulation for GPS is now divided between DoD and DoT as a result of the JTF recommendations. The DoD is responsible for the military policy, the DoT for U.S. civil government policy. There is no single coordination of international policy on GPS; the international process is fragmented among several agencies described later.

DoD retains policy and decisionmaking authority for management of the basic GPS, the Precise Positioning Service (PPS), military uses of GPS, and funding requirements. Within DoD, GPS policy is set by the Office of the Secretary of Defense, with assistance from the DoD Positioning/Navigation (Pos/Nav) Executive Committee. The DoD Pos/Nav Executive Committee, chaired by the Under Secretary for Acquisition Technology, is supported by a Pos/Nav Working Group, which carries out the committee's decisions, identifies problem areas, assists in revising the Federal Radionavigation Plan (FRP), and provides recommendations to the committee. The Executive Committee also receives input from all the commands, departments, and agencies within DoD.

Civil Management. DoT is responsible for overseeing the civil uses of GPS. As the lead DoT agency for civil GPS service operations and the government point of contact for civil users of GPS, the Coast Guard manages and operates the Civil GPS Service (CGS) program, which consists of four main elements:

- The Civil GPS Service Interface Committee (CGSIC) serves as a forum for exchanging technical information and collecting information on the needs of the civil GPS user community. The committee, comprised of representatives from private, government, and industry user groups, both U.S. and international, meets semiannually.
- The Navigation Information Service (NIS) (formerly the GPS Information Center) provides GPS status information to all users of the system 24 hours a day.

⁵⁶An example of this is the Coast Guard Differential GPS network currently being installed to meet a previously unsatisfied 8–20 meter harbor and harbor approach navigation requirement.

- The Precise Positioning Service Program Office (PPSPO) administers the program allowing qualified civil users access to the PPS signal.
- A differential GPS (DGPS) being developed by the Coast Guard augments the GPS Standard Positioning Service and will provide accuracies of 10 meters or better for civil users in the maritime regions of the United States once it becomes operational in 1996.

Oversight responsibility for GPS policymaking in DoT was recently assigned to the DoT Pos/Nav Executive Committee, established in 1994 as part of a DoT reorganization and in response to a JTF recommendation. Thus GPS responsibilities were consolidated within the office of the Assistant Secretary for Transportation Policy, who is also the designated chair of the DoT Pos/Nav Executive Committee. DoT was assigned responsibility for GPS policy relative to GPS augmentations, the SPS, all civil uses, and implementation of cost-recovery mechanisms. The committee, composed of policy-level representatives from 16 DoT offices and modal administrations including the FAA and Coast Guard, formulates coordinated policy recommendations for the Secretary of Transportation, provides policy and planning guidance to DoT's operating administrations on navigation and positioning issues, coordinates with similar committees in other government agencies, and provides unified departmental comments on the proposed rulemaking of other governmental agencies regarding navigation and positioning issues.

Two organizations provide input on civilian GPS activities to the DoT Pos/Nav Executive Committee:

- A GPS Interagency Advisory Council (GIAC) was recently established to identify and coordinate civil GPS positioning and timing issues for federal civil agencies.⁵⁷ GIAC serves as a policy arm to the DoT Pos/Nav Executive Committee, reporting policy issues relative to these GPS applications on behalf of federal agencies.
- The Civil GPS Service Interface Committee (CGSIC) (described above) has a more information-gathering and dissemination role. The CGSIC provides the DoT Pos/Nav Executive Committee information on GPS requirements from relevant private industry, government, and GPS civil user groups in the United States and overseas. Both the CGSIC chair and GIAC chair are members of the DoT Pos/Nav Executive Committee.

⁵⁷Formed in response to a JTF recommendation, the GIAC is housed within the Federal Geographic Data Committee (FGDC) and is chaired by the FGDC's Federal Geodetic Control Subcommittee (FGCS). The FGCS is responsible for federal surveying, geodesy, and related spatial activities.

Although the Joint DoD/DoT Task Force anticipated that the DoD and DoT Pos/Nav Executive Committees would work closely together to facilitate routine coordination and management decisions, it is too soon to judge whether the joint management structure has been effective. The Task Force also recommended creation of a top-level GPS Executive Board, composed of an assistant secretary from each department, to resolve those conflicts about joint civil and military use of GPS that could be resolved between the Executive Committees. An Executive Board has been formed, but it has not held any meetings to date.

Other Civil Government Agencies. Several civil government agencies are leading initiatives which rely on GPS. They have no direct involvement in DoD's management of GPS, but their role in managing GPS applications is worth noting:

- The FAA is responsible for planning and managing the civil aviation usage of GPS and for implementing GPS in the National Airspace System (NAS). This entails publishing the FAA Satellite Navigation Program Master Plan⁵⁸ and developing requirements for the use of GPS in NAS, including a set of appropriate standards for GPS aviation receivers and methods for air traffic control handling of GPS aircraft operations. A recent example of this was the 1993 FAA approval of GPS for use as a supplemental navigation for en route through nonprecision approach phases of flight.⁵⁹ The FAA also leads the initiative to augment the GPS SPS with a Wide-Area Augmentation System (WAAS), intended to be the primary means of navigation for all phases of flight from en route to Category I approaches once the system is operational.
- The National Geodetic Survey (NGS), housed within the Department of Commerce's National Oceanic and Atmospheric Administration, leads an initiative to develop a high-accuracy GPS-based National Spatial Reference System (NSRS) to replace the existing National Geodetic Reference System (NGRS), a U.S. coordinate system established by classical survey methods. This effort should eventually result in a single, seamless, NSRS-based spatial data infrastructure that can be accessed by U.S. mapping, surveying,

⁵⁸This plan presents the needs, scope, objectives, and other requisite planning information for the FAA's Satellite Navigation Program, including schedules for civil augmentation and operational implementation of GPS in the NAS. See U.S. Department of Transportation, Federal Aviation Administration, Satellite Program Office, *FAA Satellite Navigation Program Master Plan FY 94-99*, June 15, 1994.

⁵⁹Supplemental use means that another navigation source such as a ground-based radio aid must be monitored while GPS is being used as the primary system. In 1994, the FAA authorized GPS as a sole means of navigation provided the GPS equipment meets the criteria of Technical Standards Order C129 and is capable of Receiver Autonomous Integrity Monitoring (RAIM). RAIM is a form of GPS integrity monitoring based on the principle that a GPS receiver can detect and isolate a failed satellite by calculating multiple position solutions.

transportation, geodetic studies, and geographic information systems users.

- The Federal Geographic Data Committee (FGDC) was assigned by Executive Order⁶⁰ the responsibility of coordinating the federal government's development of a National Spatial Data Infrastructure (NSDI), an electronic index to spatial data collected across the United States, including GPS-based data. The NSDI is intended to provide a pool of current and reliable data, partnerships among data producers and users, and standards for sharing data. Rather than centralize all the information in one place, the government will link all the sites across the country where data are produced or maintained in computers using the Internet. This approach enables users to access this network of information using the Internet and find out what data exist, the quality and condition of the data, and the terms for obtaining them. The FGDC will attempt to put together a comprehensive set of core geospatial data by 2000.

The Federal Radionavigation Plan—A Joint DoD/DoT Effort. The Federal Radionavigation Plan (FRP) is the official planning and policy document for all present and future federally operated common-use radionavigation systems (i.e., systems used by both the military and civil sectors), including GPS. The FRP, jointly drafted and issued biennially by DoD and DoT,⁶¹ describes areas of authority and responsibility and provides a management structure by which the individual operating agencies can define and meet radionavigation requirements in a cost-effective manner.

The first edition of the FRP was released in 1980 in response to Congressional direction in the International Maritime Satellite (INMARSAT) Act of 1978 (P.L. 95-564), which instructed DoT and DoD to review their navigation needs and to select a mix of common-use systems that would meet requirements for accuracy, reliability, coverage, and cost while minimizing duplication of services. Since then, the FRP has served as a top-level plan for the joint coordination, implementation, and operation of all federally provided military and civil radionavigation systems used in air, space, land, and marine navigation. The primary objective of the FRP is to ensure that the DoD and the DoT work together to meet their needs and avoid unnecessary overlaps or gaps between military and civil radionavigation systems and services.

⁶⁰On April 11, 1994, President Clinton signed Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure." Published in the *Federal Register*, Vol. 59, No. 71, April 13, 1994, pp. 17671-17674.

⁶¹The federal government holds open radionavigation user conferences every two years to provide the public user community with the opportunity to comment on and provide input to the FRP.

Several formal structures within the DoD and DoT participate in the publication of the FRP. The DoD and DoT Pos/Nav Executive Committees handle the official staffing and coordination of the FRP, which is signed by both Department Secretaries. The latest edition of the FRP (the eighth) was published in May 1995.⁶²

The Military–Civil GPS Balance in the International Arena. *The Military Side.* Since 1978, ten NATO nations and Australia have participated in GPS development, working with the U.S. military through cooperative development agreements signed with the nations to establish a flow of information among the participating nations in all GPS program activities. To this end, personnel from these countries were assigned to the GPS Joint Program Office to advise on and coordinate NATO applications, development, and testing. Additional NATO countries have since become involved, and the scope of international participation is being expanded to include nations such as Israel, Korea, and Japan. Recent agreements have tended to be more operationally oriented agreements for PPS security, availability, and access. Nevertheless, none of these countries participates directly in the DoD’s management of GPS.

The Civil Side. International civil users are represented by several organizations that have a vested interest in global positioning, navigation, and/or timing. A focal issue for these organizations is the future Global Navigation Satellite System (GNSS), intended to be a worldwide position, velocity, and time determination system.⁶³ GPS will likely be the primary satellite constellation during early GNSS implementation.

The traditional major users of radionavigation aids—aviators and mariners⁶⁴—are represented internationally on radionavigation matters through the following organizations:

- The International Civil Aviation Organization (ICAO), a specialized agency of the United Nations made up of 160 member countries, represents the world’s aviation community. ICAO aims to develop the principles and techniques of international air navigation and to foster planning and developing international air transport. Although it serves as a mechanism for specifying and setting standards for the international use of aviation radionavigation aids, it has no authority for direct regulation. In recent years,

⁶²The Department of Defense and Department of Transportation, *1994 Federal Radionavigation Plan*, National Technical Information Service: Springfield, VA, DOT-VNTSC-RSPA-95-1 or DOD-4650.5, May 1995.

⁶³The GNSS will consist of one or more satellite constellations, end-user receiver equipment, and a system integrity monitoring function.

⁶⁴There is no comparable international organization for land users.

ICAO's Future Air Navigation Systems (FANS) committee has been evaluating medium- and long-term options for a civil GNSS. ICAO's GNSS Panel continues to work on FANS findings, including institutional and legal matters, which should result in a set of recommendations for GNSS. The FAA represents the United States at ICAO.

- The International Maritime Organization (IMO) is the maritime counterpart to ICAO. Also a specialized agency of the UN, IMO now has 136 member states. While the IMO usually refers radionavigation questions to IALA, it recently became involved in GNSS issues and set up an Intersessional Working Group of the Maritime Safety Committee to study the requirements and implementation of GNSS.
- The International Association of Lighthouse Authorities (IALA), set up in 1865 by international agreements, has 78 members and is responsible for standardizing navigation facilities, including radionavigation, in the world's coastal waters. IALA has consultative status with IMO and also has a committee studying GNSS.

Another group involved in setting standards for GNSS is the U.S.-based Radio Technical Commission for Aeronautics, Inc. (RTCA), an association of aeronautical organizations from both government and industry. RTCA operates as a Federal Advisory Committee and develops consensus recommendations on major aviation-related issues, although it has no authority in and of itself. RTCA serves as the advisory arm to the FAA on GNSS and GPS matters. In 1991, the FAA asked RTCA to form a task force to develop a consensus strategy with recommendations regarding early implementation of an operational GNSS capability in the United States. A RTCA report outlining the transition and implementation strategy for accomplishing this task was issued the following year.⁶⁵ In addition, RTCA Special Committee 159 has been meeting for several years to develop minimum operational performance standards (MOPS) for GPS equipment, which will guide the FAA in adopting appropriate regulations.

Another forum available to international users for providing input to the U.S. government regarding GPS is the CGSIC's International Information Subcommittee. Because of the importance of international GPS issues to DoT, an international representative is assigned as the vice-chair of the CGSIC. The CGSIC reports civil GPS requirements and any concerns it identifies to the Office of the Assistant Secretary of Transportation Policy.

⁶⁵RTCA, Inc., *RTCA Task Force Report on the Global Navigation Satellite System (GNSS) Transition and Implementation Strategy*, Washington, D.C., September 18, 1992.

Although the CGSIC is one avenue for GPS manufacturers to voice their concerns, in recent years the GPS industry in the United States and abroad has been organizing itself, forming associations to address its specific needs. In 1991, a group of U.S. GPS manufacturers established the USGIC initially to streamline export licensing requirements for GPS products in place at the time. Since then, the USGIC has placed emphasis on representing the industry before legislative and regulatory bodies, serving as a technical information resource to policymakers in government, and monitoring political and global issues affecting the GPS industry. USGIC membership consists of both private companies and government agencies.

A Japanese counterpart to the USGIC, the Japan GPS Council (JGPSC), was formed in 1992 primarily to avoid trade disputes between the United States and Japan.⁶⁶ Its membership is made up of private companies, associations, non-profit corporations, and universities. Its purpose is to provide Japanese companies with a forum for exchanging information with each other and with U.S. counterparts. The council provides input to Japanese government agencies, works on standardization issues, and attempts to develop the market by organizing conferences and increasing public awareness of GPS applications.

European manufacturers and public agencies have expressed an interest in creating a counterpart to the U.S. GPS Industry Council and the Japan GPS Council, although currently there is no Europe-wide organization that specifically represents the GPS industry. However, the Norwegian GNSS Industry Foundation (NGIF), formed in 1995, shares aims and objectives similar to those of USGIC and JGPSC and plans to work closely with these two organizations. Efforts are also under way to establish a European GPS user forum.⁶⁷ The Tripartite Group, which intends to develop a European Geostationary Navigation Overlay Service (EGNOS) similar to the FAA's Wide-Area Augmentation System (WAAS),⁶⁸ is forming an ad hoc group to study the possible structure for this user forum and plans to survey the private sector regarding its user requirements.

⁶⁶Kate Pound Dawson, "Japan Forms GPS Council to Avoid Tension with U.S. Firms," *Space News*, November 30–December 6, 1992, p. 6.

⁶⁷Interview with Christopher Ross, Transportation Representative for the European Union, Delegation of the European Commission, June 16, 1995.

⁶⁸The Tripartite Group consists of the European Space Agency, EUROCONTROL, and the Commission of the European Communities.

CHRONOLOGY OF GPS HISTORICAL EVENTS

Date	Event
1920s	Origins of radionavigation
Early WW II	LORAN, the first navigation system to employ time-difference-of-arrival of radio signals, is developed by the MIT Radiation Laboratory. LORAN was also the first true all-weather position-finding system, but is only two-dimensional (latitude and longitude).
1959	TRANSIT, the first operational satellite-based navigation system, is developed by the Johns Hopkins Applied Physics Laboratory (APL) under Dr. Richard Kirschner. Although Transit was originally intended to support the U.S. Navy's submarine fleet, the technologies developed for it proved useful to the Global Positioning System (GPS). The first Transit satellite is launched in 1959.
1960	The first three-dimensional (longitude, latitude, altitude) time-difference-of-arrival navigation system is suggested by Raytheon Corporation in response to an Air Force requirement for a guidance system to be used with a proposed ICBM that would achieve mobility by traveling on a railroad system. The navigation system presented is called MOSAIC (Mobile System for Accurate ICBM Control). The idea is dropped when the Mobile Minuteman program is canceled in 1961.
1963	The Aerospace Corporation launches a study on using a space system as the basis for a navigation system for vehicles moving rapidly in three dimensions; this led directly to the concept of GPS. The concept involves measuring the times of arrival of radio signals transmitted from satellites whose positions are precisely known. This gives the distances to the known satellite positions—which, in turn, establishes the user's position.

- 1963 The Air Force begins its support of the Aerospace study, designating it System 621B. By 1972, the program has already demonstrated operation of a new type of satellite-ranging signal based on pseudo-random noise (PRN).
- 1964 Timation, a Navy satellite system, is developed under Roger Easton at the Naval Research Lab (NRL) for advancing the development of high-stability clocks, time-transfer capability, and 2-D navigation. Timation's work on space-qualified time standards provided an important foundation for GPS. The first Timation satellite is launched in May 1967.
- 1968 DoD establishes a tri-service steering committee called NAVSEG (Navigation Satellite Executive Committee) to coordinate the efforts of the various satellite navigation groups (Navy's Transit and Timation programs, the Army's SECOR or Sequential Correlation of Range system). NAVSEG contracted a number of studies to fine-tune the basic satellite navigation concept. The studies dealt with some of the major issues surrounding the concept, including the choice of carrier frequency (L-Band versus C-Band), the design of the signal structure, and the selection of the satellite orbital configuration (a 24-hour figure 8s constellation versus "Rotating Y" and "Rotating X" constellation).
- 1969–1972 NAVSEG manages concept debates between the various satellite navigation groups. The Navy APL supported an expanded Transit while the Navy NRL pushed for an expanded Timation and the Air Force pushed for an expanded synchronous constellation "System 621B."
- 1971 L2 frequency is added to the 621B concept to accommodate corrections for ionospheric changes.
- 1971–1972 User equipment for the Air Force 621B is tested at White Sands Proving Ground in New Mexico. Ground and balloon-carried transmitters simulating satellites were used, and accuracies of a hundredth of a mile demonstrated.

- April 1973 The Deputy Secretary of Defense determines that a joint tri-service program be established to consolidate the various proposed positioning/navigation concepts into a single comprehensive DoD system known as the Defense Navigation Satellite System (DNSS). The Air Force is designated the program manager. The new system is to be developed by a joint program office (JPO), with participation by all military services. Colonel Brad Parkinson is named program director of the JPO and is put in charge of jointly developing the initial concept for a space-based navigation system.
- August 1973 The first system presented to the Defense System Acquisition and Review Council (DSARC) is denied approval. The system presented to DSARC was packaged as the Air Force's 621B system and therefore not representative of a joint program. Although there is support for the idea of a new satellite-based navigation system, the JPO is urged to broaden the concept to include the views and requirements of all the services.
- December 17, 1973 A new concept is presented to DSARC and approval to proceed with what is now known as the NAVSTAR GPS is granted, marking the start of concept validation (Phase I of the GPS program). The new concept was really a compromise system negotiated by Col. Parkinson that incorporated the best of all available satellite navigation system concepts and technology. The approved system configuration consists of 24 satellites placed in 12-hour inclined orbits.
- June 1974 Rockwell International is chosen as the satellite contractor for GPS.
- July 14, 1974 The very first NAVSTAR satellite is launched. Designated as Navigation Technology Satellite (NTS) number 1, it is basically a refurbished Timation satellite built by the NRL. The second (and last) of the NTS series was launched in 1977. These satellites were used for concept validation purposes and carried the first atomic clocks ever launched into space.

- 1977 Testing of user equipment is carried out at Yuma, Arizona.
- February 22, 1978 The first Block I satellite is launched. A total of 11 Block I satellites were launched between 1978 and 1985 on the Atlas-Centaur. Built by Rockwell International as developmental prototypes, the Block Is were used for system testing purposes. One satellite was lost as a result of a launch failure.
- April 26, 1980 The first GPS satellite to carry Integrated Operational Nuclear Detonation Detection System (IONDS) sensors is launched.
- 1982 A decision to reduce the GPS satellite constellation from 24 to 18 satellites is approved by DoD following a major program restructure brought on by a 1979 decision by the Office of the Secretary of Defense to cut \$500 million (approximately 30 percent) from the budget over the period FY81–FY86.
- July 14, 1983 The first GPS satellite to carry the newer Nuclear Detonation Detection System (NDS) is launched.
- September 16, 1983 Following the Soviet downing of Korean Air flight 007, President Reagan offers to make GPS available for use by civilian aircraft, free of charge, when the system becomes operational. This marks the beginning of the spread of GPS technology from military to civilian aircraft.
- April 1985 The first major user equipment contract is awarded by the JPO. The contract includes research and development as well as production options for 1-, 2-, and 5-channel GPS airborne, shipboard, and manpack (portable) receivers.
- 1987 DoD formally requests that the Department of Transportation (DoT) assume responsibility for establishing and providing an office that will respond to civil user needs for GPS information, data, and assistance. In February 1989, the Coast Guard assumes responsibility as the lead agency for the Civil GPS Service.

- 1984 Surveying becomes the first commercial GPS market to take off. To compensate for the limited number of satellites available to them early in the constellation's development, surveyors turned to a number of GPS accuracy enhancement techniques including differential GPS and carrier phase tracking.
- March 1988 The Secretary of the Air Force announces the expansion of the GPS constellation to 21 satellites plus 3 operational spares.
- February 14, 1989 The first of 28 Block II satellites is launched from Cape Canaveral AFS, Florida, on a Delta II booster. The Space Shuttle had been the planned launch vehicle for the Block II satellites built by Rockwell. Following the 1986 Challenger disaster, the JPO reconsidered and has since used the Delta II as the GPS launch vehicle. Selective availability (SA) and anti-spoofing (AS) become possible for the first time with the Block II design.
- June 21, 1989 Martin Marietta (after buying out the General Electric Astro Space division in 1992) is awarded a contract to build 20 additional "replenishment" satellites (Block IIR). The first Block IIR satellite will be ready for launch as needed at the end of 1996.
- 1990 Trimble Navigation, the world leader in commercial sales of GPS receivers, founded in 1978, completes its initial public stock offering.
- March 25, 1990 DoD, in accordance with the Federal Radionavigation Plan, activates SA—the purposeful degradation in GPS navigation accuracy—for the first time.
- August 1990 SA is deactivated during the Persian Gulf War. Factors that contributed to the decision to turn SA off include the limited three-dimensional coverage provided by the NAVSTAR constellation in orbit at that time and the small number of Precision (P)-code receivers in the DoD inventory at the time. DoD purchased thousands of civilian GPS receivers shortly thereafter to be used by the Allied forces during the war.

- 1990–1991 GPS is used for the first time under combat conditions during the Persian Gulf War by Allied forces. The use of GPS for Operation Desert Storm proves to be the first successful tactical use of a space-based technology within an operational setting.
- August 29, 1991 The U.S. government revises export regulations, making a clear delineation between military and civil GPS receivers. Under the revised regulations, military receivers continue to be treated as “munitions” with strict export restrictions, while civilian receivers are designated “general destination items” available for export without restrictions.
- July 1, 1991 SA is reactivated after the Persian Gulf War.
- September 5, 1991 The United States offers to make GPS standard positioning service (SPS) available beginning in 1993 to the international community on a continuous, worldwide basis with no direct user charges for a minimum of ten years. The offer was announced at the Tenth Air Navigation Conference of the International Civil Aviation Organization (ICAO).
- September 1992 The United States extends the 1991 offer at the 29th ICAO Assembly by offering SPS to the world for the foreseeable future and, subject to the availability of funds, to provide a minimum of six years advance notice of termination of GPS operations or elimination of the SPS.
- December 8, 1993 The Secretary of Defense formally declares Initial Operational Capability of GPS, signifying that with 24 satellites in orbit, GPS is no longer a developmental system and is capable of sustaining the 100-meter accuracy and continuous worldwide availability promised SPS users.
- February 17, 1994 FAA Administrator David Hinson announces GPS as the first navigation system approved for use as a stand-alone navigation aid for all phases of flight through nonprecision approach.

- June 2, 1994 FAA Administrator David Hinson announces termination of the development of the Microwave Landing Systems (MLS) for Category II and III landings.
- November 1994 Orbital Sciences Corp., a leading maker of rockets and satellites, agrees to purchase Magellan Corp., a California-based manufacturer of hand-held GPS receivers, in a stock swap worth as much as \$60 million, bringing Orbital closer to its goal of becoming a satellite-based two-way communications company.
- June 8, 1994 FAA Administrator David Hinson announces implementation of the Wide-Area Augmentation System (WAAS) for the improvement of GPS integrity and availability for civil users in all phases of flight. Projected cost of program is \$400–500 million; it is scheduled to be implemented by 1997.
- October 11, 1994 The Department of Transportation Positioning/Navigation Executive Committee is created to provide a cross-agency forum for making GPS policy.
- October 14, 1994 FAA Administrator David Hinson reiterates the United States' offer to make GPS-SPS available for the foreseeable future, on a continuous, worldwide basis and free of direct user fees in a letter to ICAO.
- March 16, 1995 President Bill Clinton reaffirms the United States' commitment to provide GPS signals to the international civilian community of users in a letter to ICAO.

GPS COSTS

The various estimates for the cost of GPS that have appeared in GPS-related literature often fail to specify clearly what is included in the cost figure. A recent estimate by DoD puts the total GPS program cost at \$14 billion (in 1995 dollars). This figure is based on data from the *Selected Acquisition Report* (SAR), the primary means by which DoD reports the status of major DoD acquisition programs to Congress.⁶⁹ This estimate includes costs associated with the development and deployment of all planned GPS satellites through Block IIF and with the development and acquisition of military user equipment, from program inception in FY 1974 through FY 2016. The GPS satellite and user equipment costs are shown in Table B.1. For a detailed breakdown of these costs over time, see Figures B.1 and B.2.

Additional GPS-Related Costs

The DoD definition of GPS system cost does not include the cost of launching the satellites. However, the ability to replace a GPS satellite once it fails in orbit is crucial to sustaining minimum GPS services and therefore warrants including booster and launch costs in the total cost of GPS. In this appendix we attempt to identify these costs, but industry proprietary concerns resulted in some gaps in the data. Also included here in the definition of system cost are costs

Table B.1
Basic GPS System Costs (1974–2016)
(constant 1995 dollars in millions^a)

Cost Category	FY74–95	FY96 ^b	FY97 ^b	Balance to Complete	Total
Satellite	\$3,897	\$179	\$225	\$4,264	\$8,565 ^c
User Equipment	\$3,277	\$315	\$378	\$1,554	\$5,524 ^d
Total	\$7,714	\$494	\$603	\$5,818	\$14,089

SOURCE: December 1994 *Selected Acquisition Report* (SAR).

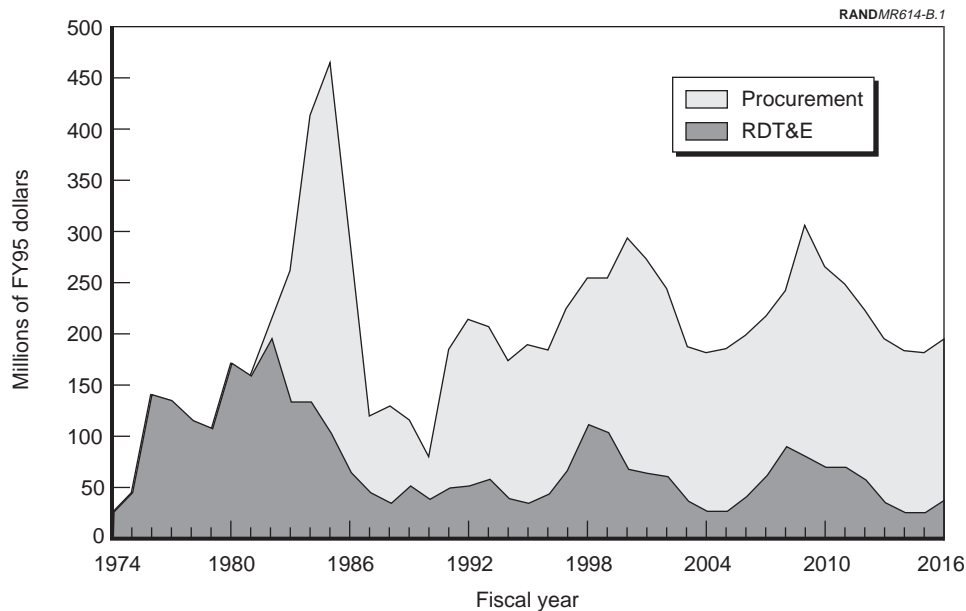
^aThe SAR reports these figures in then-year dollars. They are adjusted to 1995 dollars here using DoD deflators.

^bEstimated.

^cFor 118 satellites.

^dFor 161,298 user equipment sets.

⁶⁹*Selected Acquisition Report* (RCS:DD-COMP(Q&A)823) for the NAVSTAR GPS Program, as of December 31, 1994.



SOURCE: December 1994 *Selected Acquisition Report (SAR)*.

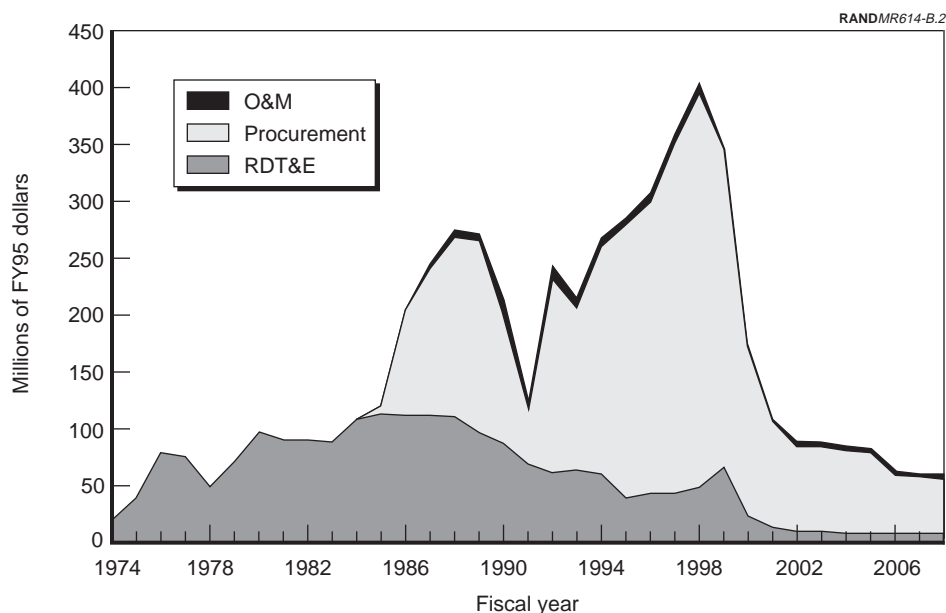
Figure B.1—GPS Satellite Costs over Time

associated with nuclear detonation detection system sensors (often referred to as NDS or NUDET), which are carried on board GPS satellites as a secondary payload. Both costs were not included in the data presented in Table B.1. By including launcher and NDS costs, the total cost of the GPS program rises to almost \$22 billion through 2016. As shown in Table B.2, more than \$8 billion of this total has already been spent.

Launch Costs

Data on the cost of launching GPS satellites are not maintained separately. Nevertheless, the GPS Joint Program Office (JPO) provided approximated cost figures for launching GPS satellites, which are included in Table B.2 and are broken down by the type of launch vehicle that have been used for GPS.⁷⁰ The first GPS satellites (Block Is) were launched on Atlas boosters between 1977 and

⁷⁰Cost figures for the Delta II launches are approximations provided by the JPO. Precise data on Delta II costs are not available at this time. A court injunction against the Air Force by the contractor (McDonnell-Douglas) prohibits public disclosure of this information.



SOURCE: December 1994 *Selected Acquisition Report (SAR)*.

Figure B.2—GPS User Equipment Costs over Time

1985.⁷¹ Since 1989, the Delta II booster has been the launch vehicle for GPS satellites and is planned for use through the completion of the Block IIR satellites. The follow-on set of GPS satellites, the Block IIFs, will be launched on a new space vehicle known as the Evolved Expendable Launch Vehicle (EELV), which the Air Force hopes to develop by 2000. At the time of publication of this report, estimates for the cost of launching the Block IIF satellites on the EELV were not available.⁷²

The Nuclear Detection System (NDS or NUDET)

Since 1980, GPS satellites have carried a secondary payload consisting of nuclear detonation sensors that provide worldwide, near-real-time, three-dimensional location of nuclear detonations. The GPS Nuclear Detonation

⁷¹Our cost data for the Atlas launches are based on figures published in the National Academy of Public Administration and the National Research Council, *The Global Positioning System: Charting the Future—Full Report*, National Academy of Public Administration, Washington, D.C., May 1995. However, the original source of these data was the GPS Joint Program Office.

⁷²The budget for development of the EELV is \$2 billion. For further information, see “U.S. Eyes Launchers With No Mil Specs,” *Aviation Week & Space Technology*, p. 30.

Detection System is managed as a joint program of the U.S. Air Force and the Department of Energy (DoE). The Air Force provides the “platform”—the GPS satellites—and operates the system; DoE provides the sensors through its national laboratories, Sandia and Los Alamos. The costs associated with the NDS sensors were provided by the JPO and are included in Table B.2. Both the DoD and DoE costs are included in these figures.

Table B.2
GPS Costs Through 2016: Basic System, Launcher, and Nuclear Detection System^a
(then-year dollars in millions)

Cost Category	FY74–95	FY96 ^b	FY97 ^b	Balance to Complete	Total
Satellite	\$3,351	\$221	\$285	\$7,306	\$11,163
User Equipment	\$3,010	\$391	\$485	\$2,236	\$6,122
Subtotal	\$6,361	\$612	\$770	\$9,542	\$17,285
Launcher:					
Atlas	\$238				\$238
Delta ^c	\$1,289	\$177	\$177	\$1,882	\$3,465
EELV	NA	NA	NA	TBD	TBD
Subtotal	\$1,527	\$177	\$177	\$1,882	\$3,703
NDS ^d	\$429	\$82	\$63	\$199	\$773
Total	\$8,317	\$871	\$1,010	\$11,623	\$21,761

SOURCE: December 1994 *Selected Acquisition Report*, supplemented with additional data from the Joint Program Office (JPO).

^aFigures not adjusted to 1995 dollars due to data constraints.

^bEstimated.

^cData include costs for research, development, testing, and evaluation (RDT&E) as well as procurement.

^dData from 1989 through 2001 only.