Defense Standardization Program

Case Study

NAVSTAR Global Positioning System (GPS)

A Military Standard Transforms Global Navigation

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On rare occasions military standards have the power to transform how the world does business. One military system, the NAVSTAR (Navigation Satellite Timing and Ranging) Global Positioning System (GPS), is an example. It helped transform military strategy and logistics, affected many commercial industries, and became the worldwide standard for navigation.

This case study demonstrates the far-reaching benefits of strategic standardization. Strategic standardization is the use of standard items across different weapon systems, Military Services, or applications to achieve strategic objectives such as interoperability, logistics readiness, or cost savings. GPS, the largest avionics procurement and installation program in the history of DoD, illustrates how strategic standardization can have global impact. When integration and installation are complete, GPS will be

- in the hands of every warfighter,
- available in about 18,000 aircraft (more than 100 different types, models, and series), and
- on board most other weapon systems that include 435 ships, 35,000 vehicles, and numerous precision guided weapons.

GPS is a government developed and operated system of satellites, ground stations, and user equipment that provides accurate position, velocity, and time (PVT) information to government and civilian users. In 1983, after the Soviet Union shot down Korean Flight 007 when it accidentally strayed across Soviet airspace, President Ronald Reagan issued a directive that made GPS receiver and signal specifications available to the public. This act opened the doors to open-market competition for the design and manufacture of GPS equipment and fostered an estimated $8 billion global market for GPS-related goods and services, a demand that doubles every 3 years. The development of civilian and industrial GPS receivers had important military benefits. During the Persian Gulf War, the military need for GPS equipment exceeded the supply available in the military inventory. Because the receiver design was in the public domain, the military was able to obtain the additional units it needed through the commercial market.

By providing precise, instantaneous PVT information anywhere on the globe at any time, in any weather, GPS, designed for a military need, now serves a broad range of civilian industries including construction, agriculture, mining, transportation, and telecommunications.

Because the U.S. government realized the vast potential of the technology and allowed free public use of the signal and receiver design specifications, GPS became the worldwide navigation standard. GPS is available for all nations, making it possible for developed and developing nations alike to benefit in the areas of safe aviation, maritime navigation, precise time distribution, and many other applications.

GPS Development History

During the Cold War (1945–1991), DoD needed precise navigation and positioning capabilities to accurately strike enemy missile silos and other targets. GPS provided the solution. Navigation and positioning have always been difficult to accomplish, and no other system has approached the ease and accuracy of GPS.

GPS is standard equipment for military aircraft

Throughout the 1960s, the Navy and Air Force worked on numerous systems that could provide navigation for various applications. Many of these systems were incompatible with one another. In 1973, DoD directed the Military Services to unify or standardize their systems. The result was a joint effort to develop GPS under the direction of the Joint Program Office (JPO) and the U.S. Air Force Space Division located at Los Angeles AFB, California. The first operational GPS satellite was launched in February 1989. The final satellite for Initial Operational Capability was launched in June 1993.

GPS burst into public awareness during the Persian Gulf War in 1991. The celebrated accuracy of U.S. weapons used during that conflict is due in large part to GPS. When commercial receivers were used during the conflict, no changes were required to adapt them for military use. The ability to rapidly employ commercial GPS equipment for military purposes underscored the wisdom and importance of making the technology and standards commercially available.

System Overview

NAVSTAR GPS consists of five ground stations and a space-based constellation of 24 satellites circling the earth at an altitude of 10,988 nautical miles, each transmitting standard radio signals. The NAVSTAR system permits users on land, at sea, and in the air to determine their three-dimensional position, velocity, and time 24 hours a day, 7 days a week, in all weather, anywhere in the world with precision and accuracy. The signals are so accurate that time can be figured to within 100 nanoseconds, velocity can be figured to within a fraction of a mile per hour, and location can be figured to within meters.

GPS has three segments: space, control, and user equipment. The space segment consists of satellites and the signals they emit. The GPS satellites serve as reference points in space. A user's GPS receiver can see between five and eight satellites from any point on the earth. Each satellite transmits signals that carry time and position data.

The control segment consists of one Master Control Station (MCS), located in Colorado Springs, Colorado, and several remotely controlled monitoring stations around the world that enable communication with the satellites.

Standardization and commonality reduce acquisition costs for users by spreading development costs and lowering life-cycle costs.

The user equipment segment consists of GPS receivers and related antennas, test equipment, and software used on aircraft, ships, ground vehicles, or hand carried by individuals. This segment provides users with the capability to receive, decode, and process GPS signals.

Two types of GPS service are available: Standard Positioning Service (SPS) and Precise Positioning Service (PPS), which provides the highest level of dynamic positioning accuracy. Civil users access SPS without charge or restrictions. Commercial receivers use the SPS signal. Authorized users with cryptographic equipment and keys use specially equipped PPS receivers. U.S. and Allied military, certain U.S. government agencies, and selected civil applications specifically approved by the U.S. government can use the PPS.

GPS Program

DoD directs and funds the GPS program. The JPO employs more than 400 personnel from the U.S. Air Force, U.S. Army, U.S. Navy, U.S. Coast Guard, NATO, and Australia. Through its close working relationships with the Military Services and Allies, the JPO has ensured interoperability and commonality through standardization across diverse aircraft, ground vehicles, ships, submarines, and hand-held receivers for

U.S. and Allied forces. In addition, the JPO manages the sales of GPS technology, hardware, and services for member countries. By using a standard system and a single buying activity, the United States and its Allies realize significant economies of scale and buying leverage, lowering total ownership cost.

Standardization Goals, Concepts, and Lessons Learned

The GPS program illustrates several important standardization concepts and lessons. GPS is a classic example of the government developing and fielding a new standards-based technology for defense with far-reaching applications for many different government and civilian purposes. The following are a few standardization concepts learned from GPS that support standardization goals: interoperability, logistics readiness, and low total ownership cost (Table 1).

Standardization supports interoperability, logistics readiness, and low total ownership cost.

GOAL 1: INTEROPERABILITY	
High-Level Standardization Across Platforms and Services	GPS receivers are designed to operate in a host of different platforms and vehicles. The standard Miniaturized Airborne GPS Receiver (MAGR) can be used in more than 30 different aircraft platforms across all Military Services. The MAGR illustrates how multiple programs and different Military Services can accept one high-level standard as their common solution. Such high-level standardization requires complex collaboration, but it offers huge benefits to all concerned. While it is often difficult to reach consensus on a common solution for multiple new systems in development, greater use of high-level standardization must be a shared goal.
Standard Signals in Space	The Air Force developed and made available to everyone a standard radio navigation signal and code. This open-architecture approach enabled numerous multinational and private-sector uses of GPS.

Table 1 ***Standardization Goals and Lessons***

GOAL 1: INTEROPERABILITY (continued)	
Standard Interfaces	The early military receivers incorporated interface features and established important interface standards that persist throughout subsequent GPS applications. While standard interfaces enabled new aircraft to integrate efficiently with GPS, older legacy aircraft required additional solutions. The lack of standard interfaces available in the numerous different legacy platforms resulted in the development of several standard interface units to adapt GPS equipment to existing hardware. While using interface adaptors is not an optimum standardization solution, it may become increasingly important for integrating new technology into the existing weapon systems during their extended lives.
Dual Use	GPS is a model for dual-use systems. It is both a force multiplier for the warfighter and a versatile navigation tool for government agencies and the civilian sector.

GOAL 2: LOGISTICS READINESS	
Commonality	Commonality through standardization has been designed into the family of joint Military Service GPS user equipment. Commonality ensures that systems are easy to produce and maintain when used with diverse applications. Commonality reduces acquisition costs for users by spreading development costs, and it helps ensure low life-cycle costs. GPS military user equipment (UE) shares a high level of commonality. Eighty-two percent of system software, 75 percent of line replaceable units (LRUs) and 94 percent of shop replaceable units (SRUs) are common across user equipment sets.
Configuration Management	The JPO is responsible for system-wide configuration management, and sharing standards with our program partners helps greatly in that task. Systems engineering translates operational requirements into technical requirements, including specification and interface documents, tests, plans, and procedures. These documents in turn provide for backward compatibility, guidance, and ensure that the new systems are interoperable.

Table 1 ***Standardization Goals and Lessons (continued)***

GOAL 2: LOGISTICS READINESS (continued)	
Logistics Support	Standardization decisions helped simplify logistics support and reduce support costs. Standard interfaces and commonality helped minimize the logistics support pipeline and enabled creative support strategies. Support strategies changed from a three-level maintenance concept for early equipment to a two-level maintenance for later items. Long-term warranties will provide for contractor logistics support as government increasingly use performance standards and commercial items to meet its requirements.

GOAL 3: LOW TOTAL OWNERSHIP COST	
Minimize Costs	The combination of standard equipment, signals, and interfaces, with multilevel commonality contribute to lower total costs throughout the lives of the system components and supporting infrastructure. Best commercial practices that include warranties, vendor-based maintenance, and "throw-away" electronics are being incorporated to minimize product life-cycle cost.

Table 1 ***Standardization Goals and Lessons (continued)***

Military Benefits

GPS has numerous military applications. Receivers aboard military aircraft enable accurate all-weather navigation. GPS provides outputs that permit precision rendezvous, recovery, targeting, and weapons delivery. GPS advanced anti-jamming capabilities allow high performance under severe electromagnetic jamming conditions. Airborne receivers can track GPS signals continuously under all aircraft dynamic conditions. GPS data can be integrated readily with other onboard avionics systems that use position, velocity, and time information to achieve mission objectives in all weather and terrain conditions. Table 2 lists some specific military GPS applications and their benefits.

Hand-Held GPS Receiver

MILITARY APPLICATIONS	MILITARY BENEFITS
Military Aircraft	Facilitates precise identification of landing zones, obstacles, and targets Increases capabilities in low-level, all-weather operations
Navy Ships and Aircraft Carriers	Provides accurate update information for the inertial ship navigation systems and the Navy's Tactical Data Systems Enables tactical maneuver operations through flexible, accurate rendezvous and recovery
Submarines	Updates inertial navigation systems and clocks to improve long-term mission accuracy during extended submarine operations Enables commander to control emissions and maintain anonymity
Battlefield Fighting Forces	Enables soldiers to move and maneuver with confidence Enables interoperability with other Military Services and forces Provides field commanders with information to maintain and use more cohesive combat units Assists in targeting enemy positions and directing fire on target to achieve single-shot destruction Improves accuracy of artillery, ranger, and scout operations Improves flexible all-weather armor tactics
Guided Stand-Off Weapons	Improves accuracy and effectiveness Improves weapons guidance, penetration, maneuverability, flexibility, and survival capabilities Updates constantly on position and velocity of in-flight weapon

Table 2 ***Military GPS Applications and Their Benefits***

Standardization decisions help simplify logistics support and reduce support costs.

Civil Benefits

Civil applications include air, road, rail, and marine navigation; precision agriculture and mining; oil exploration; environmental research and management; telecommunications; electronic data transfer; construction; recreation; emergency response; and users who need precise position, velocity, and time information. Civilian uses have proliferated. GPS supports worldwide air traffic management, navigation at sea, and land transportation management. Farmers use GPS to map and tailor applications of seed and chemicals. Oil companies use GPS to identify drilling sites. GPS has become a valuable tool for scientists and engineers. Even the height of Mount Everest has been revised based on GPS data. Table 3 shows some civilian applications and their benefits.

CIVILIAN APPLICATIONS	CIVILIAN BENEFITS
Civil Aviation	Provides an inexpensive, reliable supplement to existing aircraft navigation systems in a practical, simple, and useful form Allows aircraft computers to be programmed to fly direct routes to destinations, saving fuel and time Allows increased air traffic densities, reduces delays and airport congestion, and increases safety Simplifies guidance to safe landings during instrument approaches in bad weather Increases terrain awareness, provides warning systems, and displays moving maps for pilots' situational awareness
Land Surveying and Mapmaking	Precisely locates boundaries Locates facilities, telephone poles, sewer lines, and fire hydrants Maps construction sites and property lines Provides information to manage diverse assets over large areas, including forests, mineral rights leases, and wildlife habitats Identifies changes and monitors shifting land surfaces around volcanoes and could result in better predictions of eruptions and earthquakes Maps geographical features such as flood plain boundaries, levees, and drainage ditches for relief agencies
Geographic Information Systems	Assigns codes during data collection to identify roads, streams, and other objects for comparison and analysis
Exploration	Locates sunken vessels, for example, the Titanic, and enables efficient recovery or salvage operations Aids in exploration for energy resources and mineral deposits
Scientific Field Studies	Encourages new types of geographic analyses: geologists measure expansion of volcanoes and movement along fault lines; ecologists use to map differences in a forest canopy; biologists track animals using radio collars; geographers define spatial relationships between features of the Earth's surface

Table 3 ***Civilian GPS Applications and Their Benefits***

CIVILIAN APPLICATIONS	CIVILIAN BENEFITS
Scientific Field Studies, cont.	Locates sites within satellite images to aid understanding of regional environment Documents where soil samples, fossils, and other specimen were collected in the field
Weather Forecasting	Helps economically process massive scientific data for weather maps
Space Exploration	Enables accurate satellite tracking Improves scientific observations and satellite operations Enables better control over satellite orbits Reduces need for higher rate of data collection from satellites Reduces some requirements for data processing and equipment on board satellites, making them lighter and less costly to launch Benefits future space station operation planning Simplifies satellite rendezvous and close-in maneuvers
Highways	Assists state and federal transportation authorities maintain highways Supports efficient traffic management by routing vehicles over most direct route Monitors automated vehicles used with data links to track valuable and hazardous cargo Allows delivery trucks to receive GPS signals and instantly transmit their position to a central dispatcher Reduces response time for police and fire departments Helps motorists through dashboard displays
Railroads	Replaces older, maintenance-intensive mechanical signals
Commercial Deliveries	Increases efficiency of managed fleets (e.g., taxicabs, buses, commercial trucks) by tracking and routing individual vehicles Identifies specific vehicles, trucks, or boxcars in crowded parking lots and railroad yards Tracks in real-time message couriers, package services, and cargo transports Facilitates “just-in-time” inventory management for manufacturers by identifying arriving shipments and directing deliveries

Table 3 ***Civilian GPS Applications and Their Benefits (continued)***

By making the GPS interface standard available to the entire world, the GPS program produced a global economic impact too large to calculate.

CIVILIAN APPLICATIONS	CIVILIAN BENEFITS
Communications	Improves emergency vehicle response time for calls made from cellular telephones
Search and Rescue	Helps rescue teams search for individuals lost at sea, on mountains, in deserts, and in wilderness environments Routes sea rescue vessels precisely Transmits location of disabled vehicles
Recreation	Directs hikers, campers, and hunters with more accuracy than topographical maps Allows recreational boaters to safely navigate around sandbars, rocks, and other obstacles Locates favorite fishing holes and hunting grounds
Timekeeping	Displays time accurately to within 40-billionths of a second Encourages adoption of GPS as the standard for universal coordinated time (UTC) for synchronizing everything from electrical power grids to telecommunications networks and the Internet
Agriculture	Provides accurate positioning of fertilizer application and crops harvesting Maps crop yield to accurately plan field use and fertilization Tracks herds
Law Enforcement	Provides tracking of stolen property
Commercial Fishing	Ensures repeatable location of fishing fields and recovery of lobster and crab pots Leads to reduced violations of fisheries boundaries and exclusive economic zones

Table 3 ***Civilian GPS Applications and Their Benefits (continued)***

The cost of strategic standardization that enabled a single technological solution to a shared problem was infinitesimal compared to the benefit.

Investments and Payoffs

GPS cost more than $12 billion to develop and deploy. The current annual cost for DoD to operate, sustain, and modernize the GPS is about $500 million. The cost of strategic standardization that enabled all the Military Services and our program partners to use a single technological solution to our mutual military problems was infinitesimal compared to the shared benefits. Strategic standardization provides powerful leverage for increased interoperability, improved logistics readiness, and reduced total ownership cost.

Around the world, numerous commercial users share in the benefits for a relatively small investment in receiver equipment. Receiver costs vary depending on capabilities. In 1997, merely 2 years after the GPS was declared fully operational, commercial hand-held receivers running on two AA batteries became available for about $100 each. Geodetic-quality dual-frequency receivers that were initially priced at $100,000 in the mid-1980s are now available for less than $5,000. The most sophisticated receivers now cost up to $40,000.

The development of GPS is still in its infancy. The surface of possibilities is barely scratched. Research promises even greater benefits from increasing use of GPS. Some projects seem as amazing as an Isaac Asimov science-fiction novel, for example earthquake warning systems using high-density grids of GPS monitoring stations and GPS data com-

Hand-Held GPS Receiver Being Used in the Desert

bined with computer mapping techniques that will identify and help manage natural resources. Intelligent vehicle location and navigation systems will help drivers avoid each other and congested freeways by finding more efficient routes, saving millions of dollars in gasoline and tons of air pollution. Travel aboard ships and aircraft will be safer in all weather conditions. Businesses will be able to manage their resources more efficiently, reducing consumer costs. GPS has and will change lives in many ways.

The total value of GPS is incalculable, and total dollar savings unknowable, but the potential for GPS is enormous.

Launching a GPS Satellite

Making Systems Work Together

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