GPS Reality Checks

By Dave Wells, P.Eng.

Editor's Note: The Professional Steering Committee is pleased to present the first in a series of articles highlighting some of the recent activities and accomplishments of non-cadastral disciplines. The first article, GPS Reality Checks, is brought to us by committee members Chris Gorski, OLS, and Al Koudys, OLS of the Canadian Hydrographic Service (Department of Fisheries and Oceans) who have arranged to get permission from Dave Wells to publish his commentary.

• Abstract

President Clinton signed a Presidential Decision Directive (PDD) on 28 March 1996 which sets out a comprehensive policy on the future management and use of GPS and DGPS. This policy statement is the culmination of a historical trend over the 20-year history of GPS - the struggle to find an appropriate balance between its dual roles: national security, or military, benefits, and economic and social, or civilian, benefits. This article discusses how this historical trend has developed, as several vignettes cast as "GPS reality checks ."

• Introduction

I contend that the fundamental problem with the Global Positioning System (GPS) is that its performance has consistently exceeded what was expected of it.

This has challenged those responsible for managing GPS. The evolution of GPS technology has been so successful that it has resulted in serious political and management problems. The most serious of these has been the twenty-year struggle to establish and maintain an appropriate balance between the military and civil uses to which GPS can be put. GPS management has had to adapt to new realities resulting from this technological success of GPS.

I have selected some of these "past reality checks" for examination in this article. Each reality check is presented as a vignette, in a standard format.

• Reality Check 1: C/A-code accuracy

GPS Design: The GPS pseudoranging signal designed for civilian use, the C/A-code, was designed with a chip rate which was one-tenth that of the pseudoranging signal designed for military use, the P-code.

Planned result: C/A-code GPS positioning accuracy was expected to be about 400 m (Kremer et al 1990).

Event: Initial field tests.

Reality: C/A-code GPS positioning accuracy (first generation, or Block I GPS satellites) was 20 - 40 m, and C/A code velocity measurements were a fraction of a metre per second.

"... the fundamental problem with the Global Positioning System (GPS) is that its performance has consistently exceeded what was expected of it."

Response: Intentionally dither the satellite clocks to degrade civilian velocity accuracy, and add deliberate errors to the satellite ephemerides to degrade civilian position accuracy. This process, initially called "Denial of accuracy" eventually was relabelled as "Selective Availability", or SA, and was designed into the second generation (Block II) GPS satellites. Military receivers are able to unscramble SA errors, civilian receivers are not.

• Reality Check 2: SA increased in emergencies

Design: The "SA level" or amount of degradation can be varied. The peacetime setting for SA can be dialed up (the accuracy available to civilians and hostile forces further degraded) in times of emergency, or when required for United States national security purposes.

Planned result: Non-US-military GPS accuracy will be worse in wartime than in peacetime.

Event: The Gulf War, 1990 - 1991

Reality: Military applications of GPS had far outstripped the military receiver procurement process, particularly of relatively inexpensive hand-held units to be used in vehicles and on foot. Handheld C/A code civilian receivers, easily available on short notice, were used instead.

Response: During the Gulf War, and later during the invasion of Haiti, SA was dialed down to zero or nearly zero, not dialed up.

• Reality Check 3: GPS with SA meets user needs

Design: The civilian mode of GPS, called the Standard Positioning Service, or SPS, differs from the military mode of GPS, called the Precise Positioning Service, or PPS, in two ways: SPS is degraded by SA, and uses a single signal frequency; PPS is not degraded by SA, and is a dual frequency system. SPS was designed to match the performance of existing navigation aids, as far as transportation safety is concerned.

Planned result: SPS (with SA on) will meet most civil user needs.

Event: Explosive growth in civilian GPS use for innovative transportation information systems (Electronic Chart Display and Information Systems, or ECDIS, in the marine world, Future Air Navigation Systems, or FANS, in the aviation world, and Intelligent Transportation Systems, or ITS, in the land world). These applications provide transportation safety and efficiency advantages which go far beyond that available from navigation aids which pre-date GPS. But they are also "accuracy-addicts."

Reality: Many civilian users have also become accuracy-addicts, and need (or at least want) better performance than that provided by SPS with SA dialed up to its present level, which is officially 100 metres or less horizontally, and 140 metres or less vertically (95% of the time).

Responses: There have been two responses. The first has been political - the rise of anti-SA lobby among the civilian user community, both within the United States, and internationally. The second has been a technological end-run around SA - the development of Differential GPS (DGPS) systems. SA clock dither errors affect all users identically. SA ephemeris errors affect receivers within the same region of the earth very similarly. A GPS receiver at a stationary known location can monitor SA (and other) errors and broadcast corrections to nearby users. DGPS performance is much better than SPS, even **without** SA.

• Reality Check 4: GLONASS no threat to SPS

Design: Russia has designed a system similar to GPS in most essential ways, called GLONASS (Kleusberg 1990). One difference is that the clocks in GPS satellites are better than clocks in GLONASS satellites.

Planned result: GLONASS (which has no degradation equivalent to SA) will not displace the military or commercial advantages of GPS (with SA dialed to its present level).

Event: Since the collapse of the Soviet Union, GLONASS development has continued for commercial rather than military purposes. One result has been the design of civilian receivers capable of tracking both GPS and GLONASS satellites.

Reality: A civilian GPS + GLONASS receiver achieves accuracies comparable to SPS with SA dialed to zero (NRC 1995). The intention of SA can be defeated by using such receivers.

Response: The Presidential Decision Directive (PDD) of 28 March 1996 states that:

> It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade in a manner that allows adequate time and resources for United States military forces to prepare fully for operations without SA.

"Many civilian users have also become accuracy-addicts, ..."

• Reality Check 5: DGPS is not a security threat

Design: DGPS systems require a monitor station at a known location. Hostile forces are unlikely to have the sophistication, or to make the effort, to exploit DGPS. Monitor stations can be rendered inoperative by jamming the corrections, or by detection and destruction.

Planned result: Even though DGPS performance defeats the effect of SA, DGPS poses no threat to military security.

Event: Development and widespread implementation of DGPS technology. Wide-Area DGPS (WADGPS) technology, using many widely-distributed DGPS monitor stations, communicating with each other and with users, often via communication satellites, provides DGPS services on a continental or larger scale. At least two commercial non-U.S.-controlled WADGPS services are available around the world: the Racal Skyfix system, and the Fugro Starfix II system. At least 12 agencies of the U.S. government operate permanent DGPS systems (Army Corps of Engineers, Bureau of Land Management, Coast Guard, Defense, Environmental Protection Agency, Federal Aviation Administration, Forest Service, Geological Survey, NASA, NOAA, National Science Foundation, and the St. Lawrence Seaway). Marine DGPS services have been or are being implemented by governments in over a dozen other countries (Canada, Australia, China, India, Finland, Poland, Sweden, Norway, Denmark, Germany, The Netherlands, Iceland, and South Africa). WADGPS services for aviation are planned by the United States, Canada, Australia, New Zealand, and Japan. Two companies are using add-ons to the broadcast signals of existing FM radio stations to provide Local Area DGPS (LADGPS) services in North America and around the world. Differential Corrections Inc. (DCI) has an agreement to add LADGPS to any Canadian Broadcasting Corporation FM station within whose signal coverage area there is a sufficient demand for LADGPS services. Pinpoint has an agreement with practically all other FM stations in Canada for a similar service. Each company plans to soon operate from over 100 FM stations in North America, and many more stations around the world. Clients use a DGPS correction receiver resembling a telephone paging unit. In addition to all these permanent DGPS services, users can buy and deploy at will their own small, inexpensive, reliable, easy to operate, temporary DGPS equipment, available from many U.S. and international GPS manufacturers.

Reality: The proliferation of permanent DGPS systems, and the availability of simple user-friendly equipment for temporary DGPS systems, removes barriers to the hostile use of DGPS, and greatly increases the difficulty of rendering inoperative all possible DGPS services in a region of conflict.

Response: The Presidential Decision Directive (PDD) of 28 March 1996 states that the Department of Defense will:

> Develop measures to prevent the hostile use of GPS [and DGPS]

to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses.

• Reality Check 6: GPS is the ultimate navigation system

Design: GPS is designed to meet all expected military and civilian navigation and positioning needs.

Planned result: GPS is the ultimate navigation system. There is no need for a successor system to eventually replace GPS.

Events: Many civil, commercial and scientific positioning needs which could be met by GPS are not impeded by the balance between national security benefits and economic and social benefits. Proposals are made in other countries for superior, civil, non-US-controlled successors to GPS.

Reality: Continued growth of GPS, and full realization of its economic benefits depends on better meeting civil, commercial and scientific needs.

Response: The Presidential Decision Directive of 28 March 1996 states that the United States

> will cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial and scientific users and international security interests.

• Reality Check 7: GPS controlled solely by U.S. military

Design: From the beginning GPS was designed as a dual-use technology, meeting both military and civilian needs.

Planned result: National security (military) benefits from GPS are primary. Economic and social (civilian) benefits from GPS are secondary.

Event: Demonstration of significant GPS civil, commercial and scientific benefits. In addition to marine, air and land transport uses for which GPS was intended, new applications have emerged in resource management (farming, forestry, open-pit mining), facilities management (road and rail inventory systems), geomatics, geodesy and earth science, timing and telecommunications, and recreational personal use (hiking, biking, golf). It has been estimated that the economic impact of servicing these applications (the size of the GPS supplier industry) for the North American market totals $42 billion over the decade starting in 1994, and that this would increase to $64 billion if the use of SA were discontinued (Dyment, 1995). This does not include the economic impact (efficiencies, productivity, new goods and services) of GPS within the user sector.

"It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade ..."

Reality: Pressure to find a new balance between national security GPS benefits and economic and social GPS benefits.

Responses: Starting in 1980, and updated biennially, a United States Federal Radionavigation Plan has been prepared jointly by the Departments of Defense and Transportation (representing all civilian users). Several studies were commissioned recently to suggest changes in the management and policies regarding GPS (DoD/Dot 1993; OMB 1994; NRC 1995; NAPA 1995; Rand 1995). The Presidential Decision Directive of 28 March 1996 states that GPS (and U.S. government DGPS systems) will be managed by an interagency GPS Executive Board, jointly chaired by the Departments of Defense and Transportation, and that this Board will

> consult with U.S. government agencies, U.S. industries, and foreign governments involved in navigation and positioning system research, development, operation, and use.

• Summary

The Presidential Decision Directive of 28 March 1996 has removed the uncertainties surrounding the future of GPS which in recent years had begun to affect the full exploitation of the benefits which GPS can provide. Clear policies for the future of GPS have been established. A balance between national security benefits and economic and social benefits has been struck. A process has been established for regularly reviewing this balance, taking into account military and civil concerns, both within the United States and among other nations.

It is appropriate to conclude with a final passage from the Presidential Decision Directive:

> We will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial and scientific use on a continuous, worldwide basis, free of direct user fees.

This generous gift of accurate positioning, timing, and velocity from the taxpayers and government of the United States to the rest of the world is perhaps the greatest of the successes of GPS.

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• Appendix

THE WHITE HOUSE
Office of Science and Technology Policy
National Security Council

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FACT SHEET
U.S. GLOBAL POSITIONING SYSTEM POLICY

The President has approved a comprehensive national policy on the future management and use of the U.S. Global Positioning System (GPS) and related U.S. Government augmentations.

Background

The Global Positioning System (GPS) was designed as a dual-use system with the primary purpose of enhancing the effectiveness of U.S. and allied military forces. GPS provides a substantial military advantage and is now being integrated into virtually every facet of our military operations. GPS is also rapidly becoming an integral component of the emerging Global Information Infrastructure, with applications ranging from mapping and surveying to international air traffic management and global change research. The growing demand from military, civil, commercial, and scientific users has generated a U.S. commercial GPS equipment and service industry that leads the world. Augmentations to enhance basic GPS services could further expand these civil and commercial markets.

The basic GPS is defined as the constellation of satellites, the navigation payloads which produce the GPS signals, ground stations, data links, and associated command and control facilities which are operated and maintained by the Department of Defense; the Standard Positioning Service (SPS) as the civil and commercial service provided by the basic GPS; and augmentations as those systems based on the GPS that provide real-time accuracy greater than the SPS.

"The Presidential Decision Directive ... has removed the uncertainties surrounding the future of GPS ..."

This policy presents a strategic vision for the future management and use of GPS, addressing a broad range of military, civil, commercial, and scientific interests, both national and international.

Policy Goals

In the management and use of GPS, we seek to support and enhance our economic competitiveness and productivity while protecting U.S. national security and foreign policy interests.

Our goals are to:

(1) Strengthen and maintain our national security.

(2) Encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide.

(3) Encourage private sector investment in and use of U.S. GPS technologies and services.

(4) Promote safety and efficiency in transportation and other fields.

(5) Promote international cooperation in using GPS for peaceful purposes.

(6) Advance U.S. scientific and technical capabilities.

Policy Guidelines

We will operate and manage GPS in accordance with the following guidelines:

(1) We will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial and scientific use on a continuous, worldwide basis, free of direct user fees.

(2) It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade in a manner that allows adequate time and resources for our military forces to prepare fully for operations without SA. To support such a decision, affected departments and agencies will submit recommendations in accordance with the reporting requirements outlined in this policy.

(3) The GPS and U.S. Government augmentations will remain responsive to the National Command Authorities.

(4) We will cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial and scientific users and international security interests.

(5) We will advocate the acceptance of GPS and U.S. Government augmentations as standards for international use.

(6) To the fullest extent feasible, we will purchase commercially available GPS products and services that meet U.S. Government requirements and will not conduct activities that preclude or deter commercial GPS activities, except for national security or public safety reasons.

(7) A permanent interagency GPS Executive Board, jointly chaired by the Departments of Defense and Transportation, will manage the GPS and U.S. Government augmentations. Other departments and agencies will partici-

pate as appropriate. The GPS Executive Board will consult with U.S. Government agencies, U.S. industries and foreign governments involved in navigation and positioning system research, development, operation, and use.

This policy will be implemented within the overall resource and policy guidance provided by the President.

Agency Roles and Responsibilities

The Department of Defense will:

(1) Continue to acquire, operate, and maintain the basic GPS.

(2) Maintain a Standard Positioning Service (as defined in the Federal Radionavigation Plan and the GPS Standard Positioning Service Signal Specification) that will be available on a continuous, worldwide basis.

(3) Maintain a Precise Positioning Service for use by the U.S. military and other authorized users.

(4) Cooperate with the Director of Central Intelligence, the Department of State and other appropriate departments and agencies to assess the national security implications of the use of GPS, its augmentations, and alternative satellite-based positioning and navigation systems.

(5) Develop measures to prevent the hostile use of GPS and its augmentations to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses.

The Department of Transportation will:

(1) Serve as the lead agency within the U.S. Government for all Federal civil GPS matters.

(2) Develop and implement U.S. Government augmentations to the basic GPS for transportation applications.

(3) In cooperation with the Departments of Commerce, Defense and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems.

(4) In cooperation with other departments and agencies, coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.

The Department of State will:

(1) In cooperation with appropriate departments and agencies, consult with foreign governments and other international organizations to assess the feasibility of developing bilateral or multilateral guidelines on the provision and use of GPS services.

(2) Coordinate the interagency review of instructions to U.S. delegations to bilateral consultations and multilateral conferences related to the planning, operation, management, and use of GPS and related augmentation systems.

(3) Coordinate the interagency review of international agreements with foreign governments and international organizations concerning international use of GPS and related augmentation systems.

Reporting Requirements

Beginning in 2000, the President will make an annual determination on continued use of GPS Selective Availability. To support this determination, the Secretary of Defense, in cooperation with the Secretary of Transportation, the Director of Central Intelligence, and heads of other appropriate departments and agencies, shall provide an assessment and recommendation on continued SA use. This recommendation shall be provided to the President through the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology.

Biography

Dave Wells is a Professional Engineer, and President of Canadian GPS Associates. Since 1980 he has been a faculty member in the Department of Geodesy and Geomatics Engineering (formerly Surveying Engineering) at the University of New Brunswick. For 15 years prior to that he worked at the Bedford Institute of Oceanography as an engineer and research scientist. He holds degrees in physics, engineering physics, nuclear physics, and surveying engineering, is the author of over 200 technical papers and reports, and has presented over 30 introductory courses on GPS , and 6 courses on multibeam sonar surveying in the United States, Canada, Europe and Asia.