

The Global Positioning System (GPS) is a U.S. military space system operated by the U.S. Air Force. The space segment of GPS consists of a constellation of 24 satellites that broadcast precise time signals. When the satellites are in view of a suitable GPS receiver, these signals aid position-location, navigation, and precision timing. GPS was developed by the U.S. Department of Defense and deployed over two decades at a cost of over \$10 billion. The U.S. armed forces are increasingly reliant on its signals for a variety of purposes from navigation to munitions guidance. However, over the past 10 years, GPS has evolved far beyond its military origins. It is now a worldwide information resource supporting a wide range of civil, scientific, and commercial functions, from air traffic control to the Internet. GPS has also spawned a substantial commercial industry in the United States and abroad with rapidly growing markets for related products and services.

THE POLICY PROBLEM

GPS policy issues cut across traditional boundaries, and national policy toward GPS has not kept pace with the system's rapidly expanding commercial and civilian roles. GPS is both a military and a civilian system, as well as a domestic and an international resource. Its multifaceted nature requires a complex balancing of different—and potentially competing—national interests relating to defense, commercial, and foreign policy objectives. This situation raises complex questions for U.S. policymakers, including:

- How should the United States integrate its economic and national security objectives into GPS policy decisions?
- How should the Department of Defense respond to the existence of widely available, highly accurate time and spatial data?
- What approach should the United States take toward international cooperation and competition in global satellite navigation systems?

- How should GPS and associated augmentations be governed in the future?

Clearly, policies intended to address this diverse set of questions will require trade-offs. Fashioning these trade-offs will require a clear policy direction. Given its ownership of GPS and prior experience with dual-use technologies such as computers, telecommunications, and the Internet, the United States is uniquely positioned to shape the international policy environment surrounding this increasingly important system. However, this window of opportunity is closing, as other nations become capable of fielding rival satellite navigation and position-location systems.

PURPOSE

The purpose of this study is to assist the White House Office of Science and Technology Policy and the members of the National Science and Technology Council in addressing the key questions confronting GPS policymakers. The study identifies the major GPS policy issues, highlights opportunities and vulnerabilities in the defense, commercial, and foreign-policy arenas, discusses their implications for alternative governance and funding arrangements, and makes recommendations for U.S. policy. Assessing the effects of a dual-use technology like GPS may, in turn, provide a useful model for addressing future public policy issues in other technologies that cross traditional boundaries.

HOW GPS WORKS: A BRIEF OVERVIEW¹

The Global Positioning System consists of three segments: a space segment of 24 orbiting satellites, a control segment that includes a control center and access to overseas command stations, and a user segment, consisting of GPS receivers and associated equipment.

GPS satellites transmit two different signals: the Precision or P-code and the Coarse Acquisition or C/A-code. The P-code is designed for authorized military users and provides what is called the Precise Positioning Service (PPS). To ensure that unauthorized users do not acquire the P-code, the United States can implement an encryption segment on the P-code called anti-spoofing (AS). The C/A-code is designed for use by nonmilitary users and provides what is called the Standard Positioning Service (SPS). The C/A-code is less accurate and easier to jam than the P-code. It is also easier to acquire, so military receivers first track the C/A-code and then transfer to the P-code. The U.S. military can degrade the accuracy of the C/A-code by implementing a technique called selec-

¹For a detailed description of GPS operation, see Appendix A.

tive availability (SA). SA thus controls the level of accuracy available to all users of the Standard Positioning Service.

NATIONAL SECURITY ISSUES

The key national security issue for the United States is maximizing the military benefits of GPS while minimizing its risks. Secondary issues include the emergence of ground-based DGPS stations outside U.S. control and the status of SA.

Military Risks and Benefits

The benefits of GPS are substantial. It has become an integral component of U.S. military systems, and U.S. forces rely heavily on uninterrupted access to GPS signals. GPS provides accurate positioning and navigation for all types of military equipment, including land vehicles, ships, aircraft, and precision-guided weapons. The U.S. military is moving toward high reliance on GPS, and force structure decisions are being made that assume GPS availability. These developments carry obvious benefits, but there are risks as well. In particular, the more dependent U.S. forces become on GPS, the more vulnerable they are to disruptions in access to its signals.

The wide-scale availability of highly accurate (e.g., below 15 meters) positioning has many national security implications. First, the availability of accurate positioning is not a significant factor in major nuclear threats to the United States or its allies. Nuclear adversaries in the past, such as the Soviet Union, did not need GPS. Potential nuclear adversaries are not likely to be capable of a strategic nuclear counterforce strike and do not need GPS-level accuracies to cause great damage by the use of a few nuclear weapons.² GPS-aided cruise missiles, however, appear to be good platforms for delivering chemical and biological weapons of mass destruction.

Second, GPS-aided conventional weapons represent an air defense challenge to the United States and its allies. In particular, conventionally armed GPS-aided cruise missiles may pose a significant threat to large fixed targets, but they do not threaten most mobile targets. GPS-aiding means that weapons that are able to evade U.S. defense will have a greater potential for causing significant damage. (The spread of low-observable technologies can further increase the number of hostile aerial weapons leaking through U.S. defenses. However, the hos-

²Counterforce strikes have traditionally been thought of in terms of fixed installations such as airfield and ICBM silos. As sea-launched cruise missiles (SLBMs) make up a greater share of the U.S. nuclear arsenal, U.S. vulnerability to a counterforce attack will diminish.

tile use of low-observable technologies is an independent and distinct concern from the hostile exploitation of GPS.)

Third, selective availability has little effect on the accuracy of short- and medium-range GPS-guided ballistic missiles. GPS-aiding of Third World missiles such as the Scud and No Dong 1 can improve overall accuracy by 20–25 percent, but to no appreciable effect. Most of the advantages of GPS are achieved with the SPS-levels of accuracy, however, and SA is not a significant factor. Further improvements in missile accuracy involve much greater technical challenges than being able to access GPS signals. Missile proliferation—especially the spread of ballistic missiles—is (and has been) a serious problem independent of GPS. There is no question that use of GPS may allow Third World nations to develop accurate cruise missiles, but it is equally important to note that GPS is a facilitator, not a driver, of missile proliferation. Any potential solution to the problem of missile proliferation will require military, political, and economic components and cannot be effectively addressed by GPS policy decisions alone.

Fourth, while being able to deny access to GPS signals and GPS-related augmentations is important, this should not be done to the neglect of other countermeasures such as passive defenses, mobility, and avoidance of single-point failure modes, which can greatly reduce attack effectiveness. In particular, electronic combat against GPS must be integrated into U.S. planning and routine operations.

The magnitude of the current threat associated with hostile use of GPS is minor at present; however, future threats may be greater.³ To cope with the wide range of possible future threats that may appear, the Department of Defense (DoD) should work on the development of selective GPS denial techniques for future theaters of operations. In the near term, this includes the development of tactical jammers to deny positioning and navigation information from GPS, DGPS (differential GPS-based systems), GLONASS (a Russian space-based system similar to GPS), and commercial position-location services. In addition, the United States needs to explore both active and passive defense programs against theater-area cruise missiles and ballistic missiles that may carry either conventional warheads or weapons of mass destruction.

³GPS-guided cruise missiles are likely to be the most significant future threat from the hostile exploitation of GPS. It is the marriage of GPS with other technologies such as low-observable materials, efficient turbofan engines, accurate inertial navigation systems, and weapons of mass destruction that poses the greatest threat to U.S. and allied forces.

Emergence of Differential GPS Networks

Another potential threat is emerging with the spread of DGPS networks, some with quite broad coverage areas. In the presence of such networks, potentially hostile weapons systems using GPS could emerge relatively rapidly (e.g., in 12–18 months). Thus, the United States and its allies need to plan for the possible emergence of DGPS weapons, even if widely acknowledged evidence of such systems is lacking. The threat posed by accurate GPS-aided weapons, aerial weapons in particular, is most acute for situations where the defender lacks air superiority. U.S. air power, when generated in theater, is quite formidable against any foreseeable threats.⁴ U.S. allies can be at greater risk than the United States itself, say, in the opening period of conflict before U.S. air power can be brought to bear. Thus, U.S. regional allies should have greater incentives to deter or prevent the hostile exploitation of DGPS networks.

While creating appropriate responses to threats from long-range weapon delivery systems such as cruise missiles, the United States needs to think about how it can and should shape the international environment for space-based navigation services. For example, a stable and predictable GPS policy in the United States can help promote GPS as a global standard. In the case of DGPS services that cross international boundaries, it is in the security interests of the United States to have such systems under the direct control of allies, as opposed to potential adversaries or international civil organizations. Direct control can encompass a spectrum of techniques from using encryption of the DGPS communications link to ensure access only by authorized receivers to diplomatic agreements to limit areas and times of operation when international conditions warrant.

Selective Availability

Finally, the issue of selective availability is a controversial topic for some civil and commercial GPS users who would like to see it turned off in peacetime. However, the net effect of any SA decision on commercial growth and new applications is unclear. Technical alternatives in the form of DGPS and real-time-kinematic (RTK) techniques are increasingly available to users who need accuracies better than GPS alone can provide even with SA off. Although virtually all users would like better accuracy if it was costless, the commercial GPS market is driven much more strongly by declining prices than by the demand for accuracy only.

⁴Christopher Bowie, K. Braich, L. A. Arghavan, M. Agmon, and M. E. Morris, *Trends in the Global Balance of Airpower*, RAND, MR-478/1-AF, 1995.

The ability of SA to degrade the quality of civil GPS signals can be useful in wartime, assuming U.S. forces are not reliant on civilian GPS receivers. However, the military utility of leaving SA on in peacetime is unclear. The central arguments for leaving SA on in peacetime are that doing so discourages foreign military exploitation of GPS by making the signal less accurate and reliable than military users would want, and that turning SA on would be politically difficult, even in war or crises, because civil and commercial users would have depended on it while it was off. These arguments are being overtaken by events through the spread of DGPS techniques that can circumvent SA, initially by the use of ground-based reference beacons and potentially over wide areas by the use of reference beacons on geosynchronous satellites.

These arguments also highlight the importance of regional and international agreements on how GPS and its augmentations should be managed in times of war or crises. The most difficult questions about whether or when to turn SA on do not concern attacks on the United States, but attacks on allies or third-party conflicts where U.S. interests are unclear. One can imagine regional crises in which the United States would want a range of options, from working with allies to limit the performance of GPS augmentations, to turning SA on, actively jamming GPS signals, or attacking local DGPS ground stations. These actions would be facilitated by agreements that address regional security concerns with GPS and are likely to be more important than the single decision of leaving SA on or off in peacetime.

The risk of encouraging the proliferation of GPS-aided weapons must be balanced against the benefits of GPS as a global standard for satellite-based navigation. In this balancing, a decision on SA policy must consider U.S. interests in working with others to shape the international environment for GPS—not just individual military risks and uncertain economic benefits.

COMMERCIAL ISSUES

The key commercial issue is minimizing the political risks perceived by private industry. Currently, commercial GPS firms view political risk—that is, uncertainty surrounding future policy directions—as the greatest potential threat to U.S. world leadership in GPS products and services. Government policy decisions can create risks to commercial GPS in many ways. New taxes and fees can be imposed, spectrum licenses may be difficult or impossible to get, international trade disputes can hamper access to foreign markets, and governments may impose standards that fragment global markets into less attractive sizes. The problem of standards is particularly pervasive, as it cuts across civil, commercial, and military concerns in areas such as encryption, safety certification standards, and international spectrum allocations. Rapid changes in commer-

cial GPS since the Persian Gulf War have created a strong industry interest in a national GPS policy that will provide a predictable environment for future business decisions.

The “No-Fee” Approach

The current U.S. policy of providing SPS free of direct user charges has stimulated the growth of commercial GPS applications and has been beneficial to the United States as well as the global community of users. In part, the “no-fee” approach is a technical necessity arising from the nature of GPS signals, and enforcing payments now would be difficult or impossible. This policy has minimized incentives for the entry of competitors, since it is difficult to compete against a free service.

Competition with GPS is a possibility that is sometimes raised. This seems to be unlikely provided the United States continues current GPS operating practices. Strong incentives for an alternative to GPS could be created if the United States were to fail to sustain the GPS constellation (e.g., as a result of funding instability), fail to operate GPS in a competent, reliable way (which would also put U.S. forces at risk), or attempt to charge users for access to signals, thus creating an economic niche for a competing system. GLONASS may be used as a supplement to GPS by some users, like other GPS augmentations, but it is unlikely to become a true alternative to GPS unless U.S. support of GPS falters.

Wide-Area Augmentations

The U.S. government plans to provide wide-area augmentations of GPS accuracy for aviation and maritime navigation. This has created concerns among DGPS service providers that government services will compete with them. While the economic harm from competition may be small relative to the benefits of wide-area GPS augmentations, U.S. government policy needs to find a balance between the requirements of public safety and avoiding competition with industry.

In deciding whether civil GPS accuracy augmentations should be selectively deniable, the primary concern should be to balance national security and public safety, including international acceptance. Commercial concerns are important, but of lesser national priority. International discussions are necessary to determine what types of selective denial would be both effective and broadly acceptable. Encryption is only one means of selective denial and need not be implemented if other means are available for national security purposes.

FOREIGN POLICY ISSUES

The key foreign policy issue is reassuring foreign users—especially governments—of a stable GPS policy and funding environment and continued access to GPS signals.

Reassuring Foreign Governments

Foreign governments have legitimate concerns about relying on a system controlled by the U.S. military as well as facing potential hostile uses of GPS. The greatest concerns are uses of GPS that involve public safety, such as air and sea transportation.

The GPS international environment can evolve in various ways. If the United States promotes GPS as a global standard, it must address the technology's dual-use nature through international agreements. If the United States does not actively support GPS, or becomes an unreliable steward, GPS augmentations will move forward independent of U.S. interests. The entry of foreign alternatives to GPS (e.g., GLONASS, or an INMARSAT service) will become a possibility. The United States might retain GPS for its own national security purposes, but it would risk losing the economic and diplomatic benefits accruing from past investments in GPS.

International Safeguards

The most important international safeguards for GPS involve preventing or deterring the hostile misuse of high-accuracy GPS augmentations. With the proliferation of long-range precision strike weapons, more of our allies are facing the kind of homeland strategic threat that the United States has faced for decades. The U.S. response in the case of air navigation aids was to create the SCATANA system, which provided for military control of air traffic control radars and other air navigation aids in times of war.⁵ Beginning with traditional channels, NATO and the U.S.-Japan Treaty of Mutual Cooperation and Security could be used to create international "SCATANA" procedures with respect to wide-area GPS augmentations. In the event of war or a regional crisis, the operation of GPS-based navigation aids could be modified or suspended in an orderly way.

⁵Plan for the security control of air traffic and air navigation aids (Short title: SCATANA), 32 C.F.R. § 245, 12 pp.

International Agreements

The principal problem in dealing with international GPS issues is the fact that no single organization or forum exists for addressing the full range of concerns regarding GPS or for making agreements. Foreign discussions of GPS tend to be segregated because separate communities depend on particular applications. This segregation results partly from the origins of GPS as a U.S. military system, but is also the result of domestic political constraints. For example, the Japan Defense Agency is highly constrained in its interactions with civilian ministries and it is difficult to forge a common Japanese government approach on the regional security and economic concerns arising from the spread of DGPS networks, including DGPS services provided by Japanese civil government agencies. The European Community is interested in GPS for transportation infrastructure applications, but does not have any jurisdiction over military matters. Similarly, NATO and the Western European Union are interested in the military benefits of GPS, but have difficulty addressing civil and commercial applications in a common forum.

The United States can have a unique role in creating and shaping an international dialog on GPS issues. Statements of U.S. intentions regarding GPS, as in the Federal Radionavigation Plan or by the FAA to the International Civil Aviation Organization (ICAO), are unlikely to be sufficient to reassure foreign governments; more formal mechanisms for making commitments are needed. Such commitments are not vital to private-sector acceptance, as demonstrated by current GPS export sales, but can help accelerate civil and commercial usage. International agreements other than treaties are feasible and perhaps the most effective means of overcoming foreign government objections to the official use of GPS and related augmentations.

A U.S. commitment to provide a specific level of GPS service can be verified by international integrity monitoring. Such monitoring may limit liability for accidents involving GPS, as timely warnings can be considered a form of “real-time” notice (especially relevant to international civil aviation). International integrity monitoring would not appear to compromise U.S. security interests, and the United States could agree to refrain from actively interfering with such monitoring.

To reach a sufficiently attractive international agreement, the United States could also consider turning SA off in peacetime. By sufficiently attractive, we mean an agreement that in toto provided significant national security or economic benefits to the United States. This prospect is likely to be easier in the course of bilateral discussions with traditional friends and allies such as Japan and Europe than in a multilateral negotiation affecting only one category of GPS users, such as civil aviation. On the other hand, U.S. allies may wish to see

SA kept on, so that they are able to control access to higher accuracy signals via their own GPS augmentations.

GOVERNANCE OF GPS AND AUGMENTATIONS

Given the worldwide popularity of GPS applications, the future governance of GPS is of interest to users in the United States and overseas. Aspects of governance include ownership, control, funding, and management decisionmaking. The pursuit of U.S. national security and economic interests in the use of GPS does not necessarily require U.S. control over all aspects of GPS and its technologies, even if that were possible. Pursuit of such interests does, however, require the United States to decide how it will deal with GPS international cooperation and competition.

To protect its national security interests, the United States should ensure that GPS itself remains subject to its control. By GPS itself, we mean the space and the control segments, consisting of the satellites and the master control stations, and access to overseas monitoring stations. The user segment making up the burgeoning market for GPS-related equipment, applications, and services is effectively in the hands of the private sector.

Next in importance is the nature of the international regime for GPS augmentations such as the Wide-Area Augmentation System (WAAS) and local-area DGPS networks. Local-area networks are already under the control of the private sector and national governments. Such networks are not good candidates for international management because of their limited range, the strong national interests in retaining local control, and the lack of a means for enforcing international control even assuming this were desirable. Wide-area augmentations, particularly those using space-based reference stations, are another matter.

Wide-area augmentations to GPS can provide at least three major enhancements to GPS: improved integrity, improved availability, and improved accuracy. The public safety and commercial benefits of improved GPS integrity and availability would be of global benefit, and international, regional, or national governance would not harm U.S. security interests but would enhance the international acceptance of GPS. It is likely that international organizations such as ICAO and the International Maritime Organization (IMO), as well as individual nations, would want independent oversight of augmentations to GPS integrity and availability; this could be provided in international agreements on GPS.

Accuracy augmentations are a more difficult issue, and accuracy governance should remain under the direct control of the nation providing the service. At

present, the United States, Japan, Europe, and potentially Russia have the capability to provide wide-area accuracy augmentations. High levels of accuracy can pose risks to U.S. and regional security and require the development of military countermeasures. Wide-area accuracy augmentations should first be subject to bilateral agreements among the providers to address security and economic interests before considering multilateral agreements. Table S.1 summarizes the various preferred forms of GPS governance.

POLICY RECOMMENDATIONS

GPS enables unique military, civil, and commercial capabilities. The United States has an important opportunity to shape the direction of GPS applications and mitigate the risks of this new technology. Based on the questions posed in our definition of the GPS policy problem, the recommendations can be divided into four categories: the integration of U.S. economic and national security interests, the governance of GPS and its augmentations, national security, and foreign policy. Because of the dual-use nature of GPS, however, any policy decision in one of these realms has repercussions for the others.

Integrating Economic and National Security Objectives

- The United States should issue a statement of national policy (e.g., a Presidential Decision Directive) on the Global Positioning System to provide a more stable framework for public and private sector decisionmaking. This statement should identify U.S. interests and objectives with respect to GPS, address GPS management and acquisition issues, and provide guidance for the development of GPS augmentations and future international agreements.

Table S.1
Preferred Forms of GPS Governance

Regime	International	Regional	National, Bilateral	Local, Private
GPS segments				
Space/control			X	
User equipment				X
Wide-area GPS augmentations				
Integrity	X	X	X	
Availability	X	X	X	
Accuracy			X	
Local-area GPS augmentations			X	X

- The United States should initiate discussions with Japan and Europe on regional security and economic issues associated with GPS, potentially leading to international agreements. These agreements should be mutually beneficial to all parties but not involve the exchange of funds. The United States should be prepared to commit itself to providing the levels of GPS service defined in the Federal Radionavigation Plan.

Governance of GPS and GPS Augmentations

- The United States government should ensure that GPS is funded and maintained in a stable manner, free of direct user charges, to promote the adoption of GPS as a global standard for position location, navigation, and timing. The GPS space and control segments should remain under U.S. jurisdiction for the foreseeable future.
- In the case of DGPS services that cross international boundaries, it is in the security interests of the United States to have such systems under the direct national control of allies, as opposed to potential adversaries or international civil organizations.

National Security

- The DoD should reduce its reliance on civilian GPS receivers and the C/A-code for military purposes. The DoD should develop and introduce into operation GPS equipment capable of rapid, direct P-code acquisition as rapidly as practicable.
- The DoD should ensure that it can acquire GPS signals even in a challenged environment and should develop and field anti-jam receivers and antenna enhancements. The DoD should also ensure it has adequate electronic countermeasures to selectively deny GPS, GPS augmentations, and GLONASS signals to an adversary.
- Selective availability should be retained as a military option for the United States and not be turned off immediately. A decision on whether to turn SA off in the future should be made by the National Command Authority after international consultations and the demonstration of appropriate GPS and GPS augmentation countermeasures.
- The United States should not preclude or deter private DGPS services except for reasons of national security or public safety. In deciding whether civil GPS accuracy augmentations should be selectively deniable, the primary concern should be to balance national security and public safety,

while taking international acceptance into account. Commercial concerns are important, but of lesser national priority.

Foreign Policy

- The United States should work to minimize international barriers to commercial GPS-related goods and services such as proprietary standards and inadequate spectrum allocations.
- However, the United States should refrain, and encourage others to refrain, from providing wide-area augmentations of GPS accuracy until appropriate mechanisms (e.g., military countermeasures, diplomatic agreements) are identified to deal with the potential misuse or denial of high accuracies. Subject to international agreements, the United States should encourage international integrity monitoring of GPS for public safety.

The international environment for GPS can evolve in various directions depending on the nature of U.S. policy. If the United States makes active efforts to promote GPS as a global standard, then it will necessarily need to address the dual-use nature of the technology through international agreements. On the other hand, if the United States does not actively support GPS, or becomes an unreliable steward, GPS augmentations will move forward independent of U.S. interests, and this will encourage the entry of foreign alternatives to GPS (e.g., GLONASS, or an INMARSAT service). The United States could still have GPS for its own national security purposes, but it would risk losing the economic and diplomatic benefits from its past investments in GPS.