Report on Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS)

National Defense Authorization Act Fiscal Year 2017 Report to Congress: PNT *Requirements, and Analysis of Alternatives*

April 8, 2020

Homeland Security

Message from the Director, Cybersecurity and Infrastructure Security Agency (CISA)

April 8, 2020

The U.S. Department of Homeland Security (DHS), specifically the National Risk Management Center (NRMC) within the Cybersecurity and Infrastructure Security Agency (CISA), in coordination with the U.S. Department of Transportation (DOT), prepared the following report: *Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS).*

This document was compiled pursuant to the joint departmental report requirement in the *Fiscal Year* (FY) *2017 National Defense Authorization Act* (NDAA) (PUBLIC LAW 114–328, Sec.1618). Included in this report is an overview and a summary of conclusions.

- This report is submitted on behalf of DHS and represents civil PNT concerns. The U.S. Department of Defense (DOD) already submitted its report for DOD-related efforts.
- DHS is the national coordinator for the operational security of the Nation's critical infrastructure, and DOT has some sector-specific responsibility for the Transportation Sectors (Maritime, Aviation, Railways, and Roadways). DOT and DHS PNT representatives have been involved in the progress of the studies conducted, and all three departments (DHS, DOD, and DOT) have reviewed the information in the studies and this final report.
- Pursuant to congressional requirements, CISA NRMC prepared this report on behalf of the Federal government. This report used details from the requirement studies conducted in 2017 and 2018 by non-governmental organizations on behalf of DHS.
- The legislative requirements (see Section I) for "Section 1618" of the FY17 NDAA (P.L. 114-328; December 23, 2016) to provide PNT capability information to backup and complement GPS are included in this report. This report also includes the DHS conclusions from the requirements studies and the Analysis of Alternative (AoA) (non-acquisition) research conducted in 2017 and 2018. All these studies are available to Congress upon request.
- *The National Timing Resilience and Security Act of 2018* (PL 115-282) made the Secretary of Transportation responsible for establishing requirements for the procurement of a land-based, resilient, and reliable alternative timing system as a complement to and backup for the timing component of GPS, and a report to Congress setting forth a plan for such a system as well as an assessment of the advantages of such a system. This report does not intend to address this requirement, which was finalized after DHS' analysis was underway; however, the timing requirements for Federal and Critical Infrastructure users

contained in this report are applicable to any subsequent DOT effort.

The Committee leadership and/or their designated representative receiving this report are as follows:

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House Armed Services Committee

Ranking Member Mac Thornberry
House Armed Services Committee

Chairman James Inhofe
Senate Armed Services Committee

Ranking Member Jack Reed
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Ranking Member Sam Graves
House Committee on Transportation and Infrastructure

If you have any questions, please contact CISA Legislative Affairs at (703) 235-2080.

Sincerely,

Christopher C. Krebs

Executive Summary

Overview

The Global Positioning System (GPS) has become the definitive position, navigation, and timing (PNT) source in the United States due to its capabilities, availability, and lack of end user fees. These factors have led to widespread adoption of, and potential overreliance on, GPS. While other PNT systems are available, GPS' low end user cost and ubiquity have limited the adoption of other PNT systems for widespread use.

Adoption and use of PNT systems, other than GPS, are generally driven by operational needs such as accuracy, security, or availability that GPS cannot provide. These operational needs can justify the cost of other PNT services for specific critical infrastructure application. However, these additional costs also present market challenges for broader adoption of non-GNSS systems.

Industries that see the value in non-GNSS services adopt them, but without regulatory requirements or positive benefit-cost equations, adoption of non-GNSS services is unlikely. This report will provide details of the requirements for PNT and the analysis of alternatives that may drive the government's decision to move forward with investments in backup and/or complementary capabilities to GPS for Critical Infrastructure and critical commercial applications.

Purpose

"Section 1618" of the *Fiscal Year* (FY) *2017 National Defense Authorization Act* (NDAA) (P.L. 114-328; December 23, 2016) requires the U.S. Department of Homeland Security (DHS) to address the needs for a GPS backup by identifying and assessing viable alternate technologies and systems. The Homeland Security Operational Analysis Center (HSOAC) conducted an in-depth assessment of PNT systems currently used in the United States for DHS and DOT. This report is a summary and analysis of that assessment and provides recommendations for the Federal Government's next steps in efforts to increase the resilience of US Critical Infrastructure to disruption of GPS services.

Key Findings and Considerations

As detailed in section V of this report, DHS recommends that responsibility for mitigating temporary- GPS outages be the responsibility of the individual user and not the responsibility of the Federal Government. Research by HSOAC shows that users can mitigate short-term GPS disruptions (e.g., inability to read a GPS signal) with various strategies, ranging from using local backup capabilities to delaying operations until GPS is restored. The HSOAC report, *Analyzing a More Resilient National Positioning, Navigation, and Timing (PNT) Capability*,[1] provides an analysis of some mitigations used by specific industries to respond to a temporary disruption or

[1] The 2017 National Defense Authorization Act mandated a study "to assess and identify the technology-neutral requirements to backup and complement the positioning, navigation, and timing [PNT] capabilities of the Global Positioning System [GPS] for national security and critical infrastructure." DHS had HSOAC conduct this study.

loss.

Recognizing the ability to mitigate the negative impacts of temporary disruptions, the remainder of this report will primarily address mitigation against long-term or permanent disruption or loss of GPS PNT capabilities. While the probability of long-term GPS disruption is low, it is feasible, and prudent risk management demands taking steps to minimize the negative impacts of such an event.

In reviewing and analyzing HSOAC's report, DHS went beyond simply identifying system specifications and systems that could provide PNT if GPS were unavailable. The department sought to understand how the introduction of non-GNSS PNT systems would affect the security and resilience of critical infrastructures that are dependent on GPS for PNT. A special area of emphasis was to evaluate the reasons a user would choose to adopt non-GNSS services when GPS was available. Without end user adoption, the provisioning of services does not change the risk associated with loss of GPS. We frame this report through that risk analysis perspective.

Through the course of its analysis, DHS identified key findings and considerations. These findings are critical in contextualizing the department's assessment and recommendations in the critical infrastructure community and risk landscape. Below are key findings:

1. GPS is not the only source of PNT data. Other sources are currently available for purchase, and include alternate space-based systems and constellations, terrestrial beaconing systems, time-over-fiber, cellular and wireless signals, and local terrestrial systems.
2. Whatever the source of the PNT, it is incumbent on users to apply the principles found in Executive Order 13905, Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services. By applying these principles uses can reduce the risk associated with the disruption or manipulation of PNT services.
3. Unless non-GPS PNT sources are free/low-cost or provide a unique benefit deemed valuable by the user and not found in GPS and other currently available sources, there is no reason to assume users will adopt new non-GPS PNT sources more widely than they have today. However, user behavior could be modified through subsidies or regulatory requirements.
4. The critical infrastructure sectors heavily reliant on PNT (meaning disruption would cause significant costs, delays, or degradation of functions and service) include communications, information technology, transportation, emergency services, energy, surveying and mapping, and financial services.
5. The critical infrastructure sectors highlighted in this report are heavily reliant on PNT services, but their requirements differ significantly. Some sectors require very precise timing, while in others position and navigation precision is more important.
6. Critical infrastructure systems that would cease to operate due to GPS disruptions will do so because of design choices associated with a lack of information, cost, efficiency, and other considerations—not because of a lack of available options. In other words, business decisions, the lack of a Federal mandate, and potentially an underappreciation of the risk associated with GPS dependence are factors in the lack of resilience to GPS disruption.

7. New non-GPS PNT systems that are designed without considering existing PNT systems—including their capabilities, limitations, and why they were adopted in some industries and not others—may simply compete with existing systems rather than fill perceived backup gaps.
8. The position and navigation functions in critical infrastructure are so diverse that no single PNT system, including GPS, can fulfill all user requirements and applications. Because of this, DHS could not identify generic specifications for a national backup. Position and navigation backups must be application-specific and must be developed in coordination with industry owners and operators.
9. While position and navigation requirements are complex, timing requirements are simple, with a minimal acceptable precision of anywhere between 65-240 nanoseconds. This level of precision supports all critical infrastructure requirements and is expected to meet future requirements, including 5G.

Recommendations

Based on these key findings and considerations, our analysis of the current PNT ecosystem, and the goal of mitigating risk wherever possible, DHS offers the following recommendations to address the nation's PNT requirements and backup or complementary capability gaps:

1. **Temporary GPS disruptions:** End users should be responsible for mitigating temporary GPS disruptions. For example, the Federal Aviation Administration maintains sufficient PNT capabilities to assure the continued safe operation of the national airspace, albeit at a reduced capacity, during GPS disruptions. The Federal Government can facilitate this mitigation for various critical infrastructure sectors, but should not be solely responsible for it.
2. **PNT Diversity and Segmentation:** The Federal Government should encourage adoption of multiple PNT sources, thus expanding the availability of PNT services based on market drivers. Encouraging critical infrastructure owners and operators to adopt multiple PNT systems will diffuse the risk currently concentrated in wide-area PNT services such as GPS. Federal actions should focus on facilitating the availability and adoption of PNT sources in the open market.
3. **System Design:** PNT provisioning systems, assets, and services must be designed with inherent security and resilience features. Critical Infrastructure systems that use PNT services must be designed to operate through interference and to identify and respond to anomalous PNT inputs. These attributes are applicable to the PNT receivers and the systems that use them.
4. **Pursue Innovation that Emphasizes Transition and Adoption:** Incorporating PNT signal diversity into the PNT ecosystem should be pursued with an emphasis on research and development that prioritizes successful transition and adoption into existing GPS receivers, taking into account factors such as business case considerations, financial costs, technical integration, and logistical deployment.

Further explanations of these findings and recommendations are included in the body of this report.

Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS)

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I. Legislative Language

NATIONAL DEFENSE AUTHORIZATION ACT (NDAA) 17, PUBLIC LAW 114–328

Sec. 1618. backup and complementary positioning, navigation, and timing capabilities of global positioning system.

(a) STUDY.—

(1) IN GENERAL.—The covered Secretaries shall jointly conduct a study to assess and identify the technology-neutral requirements to backup and complement the positioning, navigation, and timing capabilities of the Global Positioning System for national security and critical infrastructure.

(2) REPORT.—Not later than one year after the date of the enactment of this Act, the covered Secretaries shall submit to the appropriate congressional committees a report on the study under paragraph (1). Such report shall include—

(A) with respect to the Department of each covered Secretary, the identification of the respective requirements to backup and complement the positioning, navigation, and timing capabilities of the Global Positioning System for national security and critical infrastructure;

(B) an analysis of alternatives to meet such requirements, including, at a minimum—

(i) an analysis of appropriate technology options;

(ii) an analysis of the viability of a public-private partnership to establish a complementary positioning, navigation, and timing system; and

(iii) an analysis of the viability of service level agreements to operate a complementary positioning, navigation, and timing system; and

(C) a plan to meet such requirements that includes—

(i) for each such Department, the estimated costs, schedule, and system level technical considerations, including end user equipment and integration considerations; and

(ii) identification of the appropriate resourcing for each such Department in accordance with the respective requirements of the Department, including domestic or international requirements.

(b) SINGLE DESIGNATED OFFICIAL.—Each covered Secretary shall designate a single senior official of the Department of the Secretary to act as the primary representative of such Department for purposes of conducting the study under subsection (a)(1).

(c) DEFINITIONS.—In this section:

(1) The term ‘‘appropriate congressional committees’’ means—

(A) the congressional defense committees;

(B) the Committee on Science, Space, and Technology, the Committee on Transportation and Infrastructure, and the Committee on Homeland Security of the House of Representatives; and

(C) the Committee on Commerce, Science, and Transportation and the Committee on Homeland Security and Governmental Affairs of the Senate.

(2) The term ‘‘covered Secretaries’’ means the Secretary of Defense, the Secretary of Transportation, and the Secretary of Homeland Security.

II. Background and Key Assessments

Background

Since GPS became available for civilian use, numerous studies have assessed the economic impact of GPS, vulnerabilities of GPS end user equipment, consequences of GPS disruptions, and what systems could backup and complement GPS. Detailed in the "Previous Assessments Section" is a non-exhaustive selection of previous works relevant to this effort selected to highlight the long-term concerns regarding the growing dependence on GPS. This report is a summary and analysis of the HSOAC's 2018 report, *Analyzing a More Resilient National Positioning, Navigation, and Timing (PNT) Capability*. HSOAC's report contains data and literary analyses of a large library of reference material to support their own conclusions regarding GPS dependency and PNT backups/alternate systems. DHS used HSOAC's report to inform and guide the findings and recommendations presented in this report.

Previous Assessments

1997

The Presidential Commission on Critical Infrastructure issued a report titled *Critical Foundations: Protecting America's Infrastructures*. The report stated that "[p]ossible exclusive reliance on GPS and its augmentations, combined with other complex interdependencies, raises the potential for 'single point failure' and 'cascading effects.'"[2] While this was primarily referring to the use of GPS in the national airspace, it has become increasingly more applicable to other critical functions required to operate U.S. critical infrastructure.

The findings of this report influenced the development of National Security Presidential Directive (NSPD)-39 that directed the Secretary of Transportation to:

> develop, acquire, operate, and maintain backup position, navigation, and timing capabilities that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the United States, in the event of a disruption of the Global Positioning System or other space-based positioning, navigation, and timing services, consistent with Homeland Security Presidential Directive-7, Critical Infrastructure Identification, Prioritization, and Protection, dated December 17, 2003.[3]

2011

DHS published a National Risk Estimate related to GPS stating:

> After a nine-month review, U.S. Government and private sector experts concluded that portions of the Nation's critical infrastructure are increasingly reliant on GPS and GPS-based services. In the short term, the risk to the nation is

[2] President's Commission on Critical Infrastructure Protection, *Critical Foundations: Protecting America's Infrastructures* (Washington, D.C.: United States Government, 1997), A-19.
[3] United States Government, Fact Sheet: *National Security Presidential Directive 39: U.S. Space-Based Position, Navigation, and Timing Policy* (Washington, D.C.: United States Government, 2004).

assessed to be manageable. However, if not addressed, this threat poses increasing risk to U.S. national, homeland, and economic security over the long term.[4]

2017

The semi-governmental advisory body *Innovate UK* issued a report on the economic impact to the United Kingdom associated with a five-day disruption to global navigation satellite systems (GNSS). The report estimates a daily economic impact $1.25B to the UK economy.[5]

2019

The U.S. Department of Commerce and DHS, through RTI International, estimated that the economic impacts to the U.S. economy caused by a 30-day loss of GPS would be $1 billion per day and could be 50 percent higher if the disruptions occurred at the least opportune time.[6]

Conclusions from Previous Assessments

All research as of the release of this report shows that dependence on GPS and other GNSS continues to grow. There have been no meaningful efforts to address the unabated adoption and use of GPS, and increasingly foreign GNSS, in U.S. critical infrastructure.

Though the 2017 and 2019 reports used different methodologies and assessed two economies with significantly different GDPs, they concluded that GPS disruptions would have negative impacts that would likely exceed $1 billion a day to their respective economies. As currently designed, the infrastructure in the UK and U.S. would suffer significant degradation and economic impacts should GPS or GNSS services be disrupted. Those negative economic impacts would be spread across a wide variety of critical infrastructures and a wide variety of applications of GPS or GNSS.

Both reports also confirmed the wide variety of uses and the unique ways GPS and other PNT sources are integrated in the operation of critical infrastructure that are broader than initially expected. For example, a greater economic loss is caused by disruption of cargo throughput at maritime ports that use automated container handling equipment, which require GPS to function, than from navigation issues created by the loss of GPS. Improving navigation to the port provides fewer benefits than improving the container handling equipment's ability to operate in the absence of GPS. These types of insights help determine where sources of risk lie and where to focus mitigation efforts and stimulate the availability of non-GNSS PNT services.

III. Positioning Navigation and Timing Landscape

[4] United States Department of Homeland Security, *National Risk Estimate: Risks to U.S. Critical Infrastructure from Global Positioning Disruptions* (Washington, D.C.: United States Department of Homeland Security, 2010), 3.
[5] Greg Sadlier et al., *The economic impact on the UK of a disruption to GNSS* (London, UK: London Economics, 2017), iii.
[6] Alan O'Connor et al., *Economic Benefits of the Global Positioning System (GPS) (Research Triangle*, NC: RTI International, 2019), ES-4.

Overview

Based on the research cited in the previous section and HSOAC's report, it is apparent that the long-term, global disruption of GPS capabilities would have wide-ranging negative impacts on the global economy and the daily lives of people around the world.

GPS and foreign GNSS are the primary PNT services that industries use to enhance operations. However, despite the billions of dollars invested by the United States in GPS, it does not meet all the U.S. PNT needs. Where GPS cannot fulfill end user requirements and where there are sufficient drivers (i.e., economic, safety of life, security), industries and the public sector have developed and employed additional capabilities to fill PNT gaps. This report summarizes these use cases and additional PNT technologies that are already available to address gaps in PNT services. The report highlights where additional technologies may be available.

Existing and Emerging PNT Capabilities

The following is a list of emerging and existing PNT capabilities, excluding GPS. This is not an all-inclusive list, rather it is intended to show the diversity in the PNT ecosystem.

- **Foreign GNSS (Galileo [EU], GLONASS [Russia], and Beidou [China]):** Increasingly, receiver manufacturers are including multiple GNSS constellations in their equipment. Manufacturers claim that using multiple constellations together provides better accuracy and improves operations in environments with limited sky visibility as the receiver is likely to have more satellites in view. There is also a belief that multi-constellation receivers provide resilience against failure of a single GNSS constellation. While this may be true in some respects, all GNSS are subject to the similar phenomenology that can disrupt their reception, including intentional jamming, spoofing, and natural disturbances such as ionospheric disturbance caused by space weather. The signal from a foreign GNSS could be intentionally or unintentionally compromised causing system degradation or shutdown. This feature introduces exposure to threats, particularly in the area of critical infrastructure.
- **Satellite-Based Augmentations and Ground Reference Stations:** These systems are designed to work with GPS and other GNSS to increase position and navigation accuracy. Some systems can provide real-time accuracy 100 times better than GPS alone, with some capable of delivering different levels of accuracy depending on the subscription. Industry recognizes the value of these increased capabilities, justifying the increased costs associated with more expensive receivers and subscriptions to gain access to better accuracy. Examples of public and private augmentations include:
    - Ground-Based Augmentation System and Wide-Area Augmentation System
    - StarFire (Manufacturer - John Deere)
    - OmniSTAR (Manufacturer - Trimble/Fugro)
    - CenterPoint RTX (Manufacturer - Trimble)
    - U.S. Continuously Operating Reference Stations

- TerraStar

- **Existing PNT Services:** Private companies are constantly seeking ways to deliver PNT services to meet customer needs. These services may provide complementary PNT functions to GPS by expanding PNT capabilities— including cross checks to validate data—or extending PNT services to GPS denied or degraded environments. For example, GPS/GNSS does not work indoors effectively, while other systems do. Therefore, some non-GNSS services are more suitable for location-based services in built-up areas. Of note, many of the below services would be available for a fee in contrast to GPS service, which is free to end users. The additional cost is a barrier to adopting one of the below services as a backup to GPS, and disincentives system diversity. Listed below are some of the private sector efforts to provide PNT services:
    - **Low Earth Orbit Satellites offering positioning and timing services:** This service is currently available to U.S. critical infrastructure operators for a fee. These service providers claim that this system can deliver precision time that meets all identified timing requirements in critical infrastructure. This system also offers a positioning and navigation service, however current accuracy levels are less than GPS.
    - **Metropolitan Beaconing Systems (MBS):** FirstNet is exploring the possibility of deploying a MBS to meet the Enhanced 911 requirement for 3D location of emergency calls in the largest metropolitan service areas. If fielded, and the system performs according to specifications, all critical infrastructure timing requirements in the serviced area could be met. The system may also be capable of meeting indoor and outdoor position and navigation requirements. This service would be fee based.
    - **Time Over Fiber:** Precision Time Protocol (IEEE 1588) has advanced in accuracy. New protocols have demonstrated sub-nanosecond time transfer over short distances (10s of kilometers), with sub-microsecond over greater distances. As this technology progresses, it will enable companies to offer time-as-a-service for a fee over fiber networks.
    - **High Precision Positioning:** Numerous sites around the country have deployed highly precise positioning systems that do not rely on positioning data from GPS. These systems cover limited areas but can provide positioning data significantly better than GPS. DOD, DOT, and private entities purchase these systems to meet specific operational requirements.

IV. Analysis of Alternatives

HSOAC Research indicates that critical infrastructure systems that would cease to operate without GPS do so because of design choices, cost factors, increasing efficiency, or other considerations—not because of a lack of available additional means to navigate, determine location, or synchronize. If future critical infrastructure systems are engineered and operated based on the same design choices, providing additional PNT sources will not change the risk associated with the unavailability of GPS. Unless the additional PNT services provide unique benefits deemed valuable by the user community, or regulators mandate that users secure resilience to long-term GPS failure, there is no reason to assume businesses will act differently than they do today.

In acknowledging the availability of existing and emerging PNT services, based on research conducted by HSOAC, DHS sought to determine how deployment of additional, federally supported PNT system(s) or requirements would change the risk associated with the loss of GPS for critical infrastructure. The precision of those alternative capabilities, and the analysis HSOAC used to arrive at them, are listed in subsequent sections. Following the technical specifications, this report discusses adoption-related requirements.

Timing Backup

Requirements

GPS timing is exceptionally accurate, delivering time within billionths of a second to users around the world. According to GPS.gov's website, GPS Accuracy Q&A page, "[t]he U.S. Government distributes Coordinated Universal Time (UTC) as maintained by the U.S. Naval Observatory (USNO) via the GPS signal in space with a time transfer accuracy relative to UTC (USNO) of ≤40 nanoseconds (billionths of a second), 95% of the time." Applications receive the time directly from GPS—no other inputs are required.

Based on multiple studies, the most stringent timing requirements for critical infrastructure are listed in Table 1.

Table 1

Function	Requirement
Electricity	1.0µs Phasor Measurement Unit*
Wired and Wireless Communications	1.5µs for 4G LTE Network Backbone
	50–200 Parts Per Billion Frequency Stability
Emergency Services (FirstNet)	1.5µs for 4G LTE Network Backbone
	50–200 Parts Per Billion Frequency Stability
Financial Services	50µs**

*Currently not used for operations   µs = microsecond(s) (millionth of a second)
**Regulatory requirement

The precision time delivered by GPS exceeds the need of all critical infrastructure for the foreseeable future. Cellular networks require timing accuracy of 1.5µs for 4G. As the nation transitions to 5G, those requirements may become more precise (~240 nanoseconds) but are not expected to exceed GPS's capabilities. Since the telecommunication timing requirement is nationwide and is also the most precise requirement used by critical infrastructure it can serve as a baseline requirement for timing services accuracy.

This means that any system serving as a timing backup or alternate must provide a minimum of 1.5µs accuracy and 50–200 parts per billion frequency stability to maintain support to the communications sector.

While the Electricity Sector appears to have a more stringent requirement, utilities can continue to operate without that level of precision due to their strategic implementation of timing requirements. While the electric industry has sought to benefit from the availability and precision of GPS, they have not created a dependence on GPS. Should GPS signals become unavailable, the electric grid will continue to operate. This is an effective model for the use of GPS in critical applications. The system takes advantage of increased precision to increase efficiencies while still being able to operate in the absence of GPS, albeit at reduced efficiency.

Alternative Systems

Table 2 depicts proposed timing solutions submitted by industry to DHS during a Request for Information (RFI) in December 2018. According to industry, there are several systems that can meet or exceed all timing requirements for U.S. critical infrastructure (those indicated in green). Each proposal has unique characteristics that could impact industry use. For example, some systems are available nationwide while others are local or regional (see Table 3).

*Table 2**

Proposed Solutions	Precision Timing Requirements			
	5G	**4G-LTE Network**	**Phasor Measurement Unit**	**Financial Services**
μs = microseconds	~240 Nanosec.	1.5 μs	1 μs	50 μs
eLORAN				
Locata				
Network Time Protocol				
NextNav				
Precision Time Protocol				
Satellite Time and Location (STL)				
NIST WWVB Radio				

■ Meets Precision ■ Precision within factor of 5 ■ Not close to req. precision

*System performance parameters are as reported by the submitter and have not been validated by the government. Actual system performance must be assessed as part of any acquisition effort.

Table 3

Proposed Solutions	Availability	Coverage
eLORAN	Not operational in U.S.	TBD
Locata	Commercial use	Local
Network Time Protocol	Commercial use	Local – National
NextNav	Commercial use	Regional
Precision Time Protocol	Commercial use	Local - National
Satellite Time and Location	Commercial use	National
NIST WWVB Radio	Commercial use	National

One area of concern is dependence on GPS to synchronize to UTC. Any system designed to backup or complement GPS must not have a GPS connection in its timing supply chain.

Positioning and Navigation Backup

Requirements

While determining timing requirements was relatively straight forward, position and navigation is complex with no single application, like telecommunications for timing, that can be used as a baseline for position and navigation backup capabilities. To identify the end-user requirements, HSOAC conducted market analysis and developed functional use cases to understand the level of precision required for specific applications and how those applications obtain position and navigation data.[7]

Table 4 contains the leading position and navigation applications and key capabilities enabled by GPS-based services identified in the Food and Agriculture Sector.

Table 4

Applications	GPS Mapping	GPS Piloting	Variable Rate Tech
Key Functions	• Can treat each part of the field differently • Can pinpoint problems in specific patches of land through soil and other analysis • Enables targeting of pests identified by aerial images	• Uses GPS to more accurately steer equipment • Enables farm work to extend after daylight • Can ensure equipment does not disturb crops	• Used to ensure all land has planted seeds or are not replanted • Can better target fertilizer use and apply appropriate amount • Can better use pesticides to target pests when attacking specific areas of field
Initial Metrics	Sub 1 meter (1m)	Sub 1m	Sub 1m
Fee-Based Services	Yes, software and hardware for GPS mapping is an external service	Yes, software for auto steering requires monthly or yearly subscription service; fees are $900–3,000 a month	Yes, requires yield measurements and other software to target pesticide, fertilizer, and other material application

This example shows that farmers can pay for sub-meter accuracy to enhance mapping, vehicle piloting, and variable-rate application of chemicals. To obtain these levels of precision and the enhanced efficiencies, the farmer must purchase user equipment and pay a subscription. If either GPS or the augmentation is unavailable, the ability to conduct the task is impaired. However, there are several considerations that determine whether a farm adopts precision farming.

HSOAC's research determined that other sectors and applications are also willing to pay for increased precision, such as surveying, construction, shipping (containerized), and location-

[7] The user-needs analysis (PNT data) is attached as Appendix C of this report.

based services. Not surprising, these were some of the same industries RTI International assessed to have the highest economic impacts from a GPS outage.

Provisioning Position and Navigation Services

Table 5 depicts real-time position and navigation solutions submitted by industry during the RFI process compared to examples of application-specific precision requirements. Additional comparisons are contained in HSOAC's report submitted to DHS.

*Table 5**

Real-Time Solutions	Precision Requirement Examples with Bounded Precision					
	Precision Agriculture/ Construction	**Port Operations (Automated containers)**	**Consumer LBS**	**Over the Road Navigation**	**Open Water Navigation**	**Open Water Navigation**
	<10cm	≥10cm–< 1m	1–< 5m	≥ 5–10m	10–20m	>20m
GPS (Aug)						
GPS (UnAug)						
eLORAN						
STL						
NextNav						
Locata						

■ Meets Precision ■ Precision within factor of 5 ■ Not close to req. precision

*System performance parameters are as reported by the submitter and have not been validated by the government. Actual system performance must be assessed as part of any acquisition effort.

As mentioned earlier, GPS alone cannot meet many of the precision position and navigation requirements without augmentation. Generally, any precision requirement below 5m will require some form of augmentation (this may change soon with dual frequency, carrier phase-based GNSS chips). As Table 5 depicts, only two systems can meet this requirement, but only in the areas they are deployed. Even if the backup requirements are expanded to the 5m that GPS can provide, it will not expand the available backup options or significantly reduce risk. While some position and navigation systems can outperform GPS, they are localized applications and face challenges scaling to a national or regional level (see Table 3).

Industries adopt high-precision position and navigation services only when there is a business case to do so. However, even within industries heavily dependent on precision position and navigation, not all users will adopt precision applications due to the increased cost. For example, a farm would need to be sufficiently large to offset the cost of equipment and fees associated with precision farming. A 2014 U.S. Department of Agriculture report estimated that 70 percent of U.S. farms were under 197 acres.[8] HSOAC assessed that a farm would need to have a minimum acreage between 200 and 2,100 acres to justify the expense associated with precision

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[8] United States Department of Agriculture, National Agricultural Statistics Service, *Farms and Farmland, Census of Agriculture Highlights* (Washington, D.C.: United States Department of Agriculture, 2014).

farming.[9] Consequently, it is not cost effective for 70 percent of U.S. farms to adopt precision farming. This highlights the price sensitivity associated with the adoption of additional position and navigation systems.

Understanding the Augmentation Market Space

By whatever means funded, all augmentation systems require interested investors or sponsors. In the public sector, per NSPD-39, agencies requiring augmentations to GPS are required to fund the augmentation in their budgets. In the private sector, companies have developed, and continue to develop, capabilities to deliver high-accuracy position and navigation services through GPS augmentation or other means. These services are sold to industries who are willing to pay for this level of accuracy. If the U.S. Government were to provide a free backup and complementary system, similar to the free utility of GPS, the government would have to consider the repercussions of such a system in the marketplace. A free government system would negatively impact commercially available PNT systems by directly competing with them.

V. Backup Considerations

Up to this point, this report has detailed PNT accuracy and precision requirements and the systems that can deliver PNT to meet those requirements, relying primarily on HSOAC's research. To assist with an analysis of alternatives on viable backup system(s), HSOAC delineated the risks that critical infrastructure users are attempting to mitigate and analyzed how a backup impacts said risks. DHS frames this risk in three general scenarios. This unclassified report will not discuss potential causes, only the effects on GPS and GNSS availability.

- **Scenario 1:** Signals in the GPS band are unavailable or unreliable due to spectrum interference (jamming or spoofing) within the United States. This interference is limited in geographic area and duration.
- **Scenario 2:** GPS and GNSS systems are unavailable nationwide due to events such as a geomagnetic disturbance. GPS and GNSS are expected to return to normal operations within days.
- **Scenario 3:** GPS signals are no longer available, and restoration of services cannot be determined.

Temporary Disruptions

Though the U.S. Government provides GPS for free, this does not remove the obligation of the end user to plan for its short-term disruption. Since no utility is perfectly reliable, users plan appropriately, implementing backups and contingency plans to assure continuity of business. In the case of electricity during major disasters such as hurricanes, critical functions continue despite power outages because users made appropriate contingency plans and are able to use alternate power sources until mainline power is restored. In the first two scenarios critical

[9] Richard Mason et al., *Analyzing a More Resilient National Positioning, Navigation, and Timing (PNT) Capability* (Washington, D.C.: Homeland Security Operational Analysis Center, 2019).

infrastructure users can use this traditional utility disruption mitigation approach—resorting to local power backups.

Planning for temporary disruptions can vary depending on the nature of the function. At one end of the spectrum, there are safety-of-life applications that require significant investment to enable graceful degradation and maintenance of an acceptable level of performance. Returning to the electricity example, hospitals invest significant resources ensuring backup power sources are available and maintained. On the other end of the spectrum, there are applications that will simply be deferred until signals are available, similar to retailers being unable to serve patrons until power is restored.

Long-Term Disruptions

The unique nature of GNSS systems requires the United States Government to consider a scenario where GPS and other GNSS are no longer available. Addressing this issue requires an entirely different approach to backup capabilities. Returning to the electricity model, end users assume that electricity will eventually be restored and delivered in the same format as before the disruption (direct current). Users do not plan for a backup delivery system which would necessitate not only the construction of a new distribution model, but the replacement or modification of all end user equipment. In contrast, should GNSS become unavailable and critical infrastructure be required to move to an alternate PNT source, it would not only likely require a new delivery system, but also widespread adoption of the alternate system's end user equipment, such as the procurement of upgraded receivers and antennae that would receive a signal other than GNSS.

If the Federal Government plans to require backup capabilities for a sudden, long-term disruption to GPS, the concept for a backup must change. If the Nation is to react to such an event, then there must not only be a distribution system in place, but also the end user equipment. If either the delivery method or the ability to receive the PNT data is unavailable, the system will not work. Moving users to this model will be challenging. There are three ways to influence user willingness to adopt alternate systems:

1. Availability of a PNT service that is at least as economically or operationally beneficial as GPS.
2. Require (through regulation or government policy) adoption of alternate PNT sources.
3. Availability of a non-GPS PNT service that is compatible with GPS equipment, and would be therefore transparent to most GPS users.

Option (1) represents the current operating environment where GPS is ineffective, and industry adopts alternate systems to provide PNT sources. In applications where safety-of-life requires PNT assurance, industry uses alternate and backup systems to maintain that assurance. In addition, one backup service is unlikely to meet all PNT requirements. Because of these dynamics, providing a government alternate to existing PNT systems is unlikely to significantly change the nation's risk profile unless it is heavily subsidized (and therefore anti-competitive) or there are other incentives to adopt.

Option (2) could provide incentives necessary to reduce the nation's risk profile. Currently there is no authoritative or regulatory requirement for adopting any backup or complementary system to GPS. However, the U.S. Government could regulate public/private entities that own and operate critical infrastructure assets that rely on PNT to adopt alternate sources for backup/complementary purposes. Doing so would not necessarily require fielding additional complementary PNT capabilities but it would set an outcome-oriented framework to require certain critical infrastructure to invest in resilience.

Option (3) is a different approach where government and industry would collaborate to enable behavioral and design changes to enhance resilience. For example, as foreign GNSS systems, such as Galileo, come online, industry is integrating the new systems on the same chipset and using the same antenna as GPS. By emulating form factor and not significantly changing the size, weight, and power requirements, Galileo will provide some degree of backup capability depending on the cause for disruption.

If, for example, a commercially available PNT system were integrated with existing GNSS chipsets and hardware, the U.S. Government could incentivize inclusion of these capabilities onto GNSS chipsets sold in the U.S. During normal operations, these capabilities would only be available to subscribers. Should a largescale GPS disruption occur, the government would then at least have the capability to deliver service to all users in an emergency regardless of subscription based on need. If the government pursues this option, the requirements would expand to:

- GPS and backup receivers co-exist within the current GNSS form factors.
- GPS and backup receivers are integrated on a PNT chipset.
- Antennas and other hardware support both GNSS and backup signals.
- The system can provide PNT data to all users regardless of subscription status during a long-term disruption to GPS.

If any of the systems that can meet critical infrastructure's timing requirements can be effectively integrated with GPS equipment, there could be significant risk reduction benefits for timing applications. Since none of the systems meet all position and navigation requirements, the impact to position and navigation resilience will be less substantial. To ensure widespread adoption, newly adopted systems must have capabilities matching GPS and would be more readily adopted if they provide capabilities not native to GPS.

Conclusion

The department's analysis leads it to conclude there are steps the U.S. Government can take in the near term, in concert with industry, to enhance PNT resilience that would be more effective than endorsing and investing in a single backup system. Government and industry can achieve effective risk mitigation by influencing owner and operator planning and investment, broadening education efforts about the criticality of PNT services, enabling innovation in the market space, working to promote technical interoperability and adopting the principles contained in Executive Order 13905, Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services.

Furthermore, overreliance on a government endorsed or provided system can cause negative impacts. For example, telecommunications providers deploy high-quality oscillators (clocks) that enable systems to operate without an external timing source for days, weeks, and potentially months before services are significantly degraded. If operators deploy a primary timing system (GPS), an alternate timing system (foreign GNSS), and an "un-jammable" third system endorsed by the government and paid for by the operator, will they continue to install high end oscillators? The U.S. Government must assess how businesses will react to changes in the PNT ecosystem to guard against undesirable, unintended consequences.

As the research detailed in this report demonstrates, there is no single intervention that the U.S. Government can make to ensure risk elimination of a GPS disruption. However, there are smart, market-oriented solutions that will contribute to enhanced resilience that the U.S. Government should continue to promote, enable and stimulate.

VI. Departmental Plan for Meeting the Requirements

Department of Homeland Security

Since the enactment of the FY17 NDAA, DHS has aggressively pursued efforts to define the PNT operating environment for U.S. critical infrastructure. Most of the work in this report is based on DHS efforts. Based on our findings throughout these studies, CISA has provided value-added information at various interagency and private sector outreach conferences (when available). CISA has posted Information Papers and Best Practice information on the website gps.gov. As DHS transitions from the "requirements" definition phase, the department looks to governing documents to define roles and responsibilities.

DHS will continue its efforts to fulfill requirements established in PPD-21, Critical Infrastructure Security and Resilience, as they relate to PNT. DHS will continue to work with the interagency and the private sector to identify vulnerabilities associated with use of PNT services and work to minimize the associated risk to infrastructure. Because DHS has been actively engaged in the identification and mitigation of risk associated with PNT, DHS does not foresee any significant changes to our resourcing requirements in this mission space. The department will maintain current PNT resourcing levels to support security and resilience efforts.

DHS will continue coordination with DOT to support DOT as they execute their responsibilities under the *National Timing Resilience and Security Act of 2018*.

A. List of Abbreviations/Acronyms

AoA	Assessment of Alternatives
CISA	Cybersecurity and Infrastructure Security Agency
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOT	U.S. Department of Transportation
FY	Fiscal Year
GLONASS	Globalnaya navigatsionnaya sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSOAC	Homeland Security Operational Analysis Center
LORAN	Long-Range Navigation
LTE	Long-Term Evolution
MBS	Metropolitan Beacon System
NDAA	National Defense Authorization Act
NIST	National Institute of Standards and Technology
NRMC	National Risk Management Center
NSPD	National Security Presidential Directive
PL	Public Law
PNT	Position, Navigation, and Timing
RF	Radio Frequency
RFI	Request for Information
STL	Satellite Time and Location
USNO	U.S. Naval Observatory
UTC	Coordinated Universal Time

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C. User Needs Framework

Reported User Needs for Timing Accuracy

Critical Sector	Application	Accuracy Range
Communications / Mobile Applications[10]	Billing, alarms	1 to 500 µs
	Internet Protocol delay monitoring µ	5 to 100 µs
	Call handoff/continuation[11]	10 to 30 µs
	Node-to-node communication	7 to 9 µs
	Network routers and switches, network backhaul[12]	4 to 5 µs
	Time stamping/event management	2 to 5 µs
	Long-term evolution (LTE) Time -Division Duplexing (TDD) (large cell) WiMax-TDD (some configurations)	1.5 to 5 µs
	ULTRA-TDD	1 to 1.5 µs
	LTE-TDD (small-cell)	1 to 1.5 µs
	Handoffs in WiMax-TDD (some configurations)	1 µs
Wired Communications[13]	Conversational video (livestreaming)	1 µs
	Conversational voice	150 µs
	Mission-critical data	100 µs
	Mission-critical delay sensitivity signaling	75 µs
	Vehicle-to-Everything messages	50 µs
	Network routers and switches[14]	50 µs
	Grandmaster clock[15]	1.5 µs to 50 µs
Electricity	Physical/video security	1 s
	Network security	1 µs
	Sequence of event recorder	1 µs
	Protective relays-coordinated controls	1 µs
	Phasor Measurement Unit (PMU) – offline	1 µs
Emergency Services	Public safety answering point	Sub 1 s
	Simulcast Land Mobile Radio (LMR) Systems	2 µs
	First Responder Network Authority (FirstNet)	1.5 µs
Financial Services	Manual security trading	1 s
	Automated security trading	50 µs
	Computer system clocks and time stamping	100 µs to 50 µs
	Non-high-frequency trading (ESMA MiFID-2)	1 µs
	High-frequency trading (ESMA MiFID-2)	50 µs

Source: Cavitt, et al. (2018)

[10] Applies to 20, 30, LTE-FDD, and LTE-A, except where otherwise noted.
[11] Applies to 20, 30, LTE-FDD, and LTE-A, except where otherwise noted.
[12] Violation of timing requirement expected to have relatively minor impact.
[13] Applies to Synchronous Optical Networking (SONEn, Time-Division Multiplexing (TDM), Ethernet, and ultra-high-speed Ethernet.
[14] Violation of timing requirement expected to have relatively minor impact.
[15] Violation of timing requirement expected to have relatively minor impact.

Reported User Needs for Positioning Accuracy

Critical Sector	Application	Position Accuracy Range
Chemicals	Tracking chemicals through supply chain	1-5 m
	Inspection and monitoring of equipment, pipes, and assets	Sub 1 m
	Chemical Cleanup	Sub 1 m
Commercial Facilities	Construction	Sub 1 m
	Location-based marketing and sales	Sub 5 m
Communications	Geographical service extension	Sub 5 m
	Wireless signal strength measurement	Sub 5 m
	Service and fleet management	Sub 5 m
	Public safety alert management	Sub 10 m
Dams	Monitoring deformations in dams and infrastructure (structural integrity)	1 cm horizontal 2 cm vertical
	Monitoring deformations in landforms and waterways	Sub 0.5m
	Construction of dams	Sub 10 cm
Emergency Services	Strategic deployment of resources (large incidents)	Sub 1 m
	Dispatch and routing (routine incidents)	Sub 1 m
	Public safety alert management	Sub 10 m
Energy	Seismic exploration (land and marine)	1 m for seismic exploration 10 cm for hydrographic mapping 1 m for docking
	Dynamic positioning – drilling	10 cm for dredging and construction
	Construction	1 m for cable and pipe laying
Financial Services	Tracking assets such as cash	15 m
	Risk assessment	1 m for drone to evaluate specific properties 5 to track consumer auto behavior
	Loan loss mitigation/ measurement	1 m for drone to evaluate specific properties 5 to track automotive collateral
Food and Agriculture	Mapping farms	Sub 1 m
	Piloting farm equipment	Sub 1 m
	Variable rate technology	Sub 1 m
	Food sourcing	Sub sm
	Food control	Sub sm
Government Facilities	Workforce/asset tracking	Sub 1 m
	Base planning/coordination	Sub sm
	Student tracking systems	Sub sm
	Defendant/parolee tracker	Sub 1 m
Healthcare and Public Health	Health data mapping	Sub 1 m
	Location-based services to direct patients to health services	Sub 5 m
	Telemedicine and response	Sub sm
Nuclear Reactors, Materials, and Waste	Tracking materials and waste through supply chain	1-5 m
	Inspection and monitoring of facilities	1 cm
	Monitoring crustal deformations at nuclear waste	Sub 1 m

Critical Sector	Application	Position Accuracy Range
	disposal site	
Water and Wastewater	Equipment mapping, monitoring, and tracking	Sub 1 m
	Survey and mapping of landforms and waterways	1 cm
	Fleet management	Sub 5 m

Source: Thompson, et al. (2018).

Reported User Needs for Navigation Accuracy in Transportation

Critical Sector	Application	Position Accuracy Range
Aviation	Oceanic phase of flight	7.4km
	En route flight	3.7km
	Terminal flight	750m
	Non-Precision Approach (NPA)	220m
	Approach Procedure with Vertical Guidance (APV)	16 m horizontal 20 m vertical (APV-I) 8m vertical (APV-II)
Maritime	Cat-I landing	16 m horizontal 4-6m vertical
	Cat-II landing	7.5 m horizontal 1 m vertical
	Cat-III landing	3 m horizontal 1 m vertical
Road Vehicle to Infrastructure	Ocean navigation	10m
(V21) Applications	Pot approach and restricted waters	10m
Road Vehicle to Vehicle (V2V)	Inland waterways	2-10m
Applications	Port	1m
	Road	5m
	Lane	1.1m
	Where-in-lane	0.7m
	Road	5m
	Lane	1.5m
	Where-in-lane	1.0m

Source: Tralli, et al. (2018b).