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Resilient PNT is Vital to Golden Dome Success

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Executive Summary

- The Golden Dome for America air and missile defense system, as directed by President Trump in Executive Order 14186 dated January 27, 2025, will be heavily dependent upon Position, Navigation and Timing (PNT) for its effectiveness.
- The Global Positioning System (GPS) and other space- and ground-based PNT sources have significant failure modes and vulnerabilities that can be exploited by America's adversaries.
- Urgent investments in a national, resilient PNT architecture with at least two or three sources that have markedly different failure modes are needed to address and mitigate known vulnerabilities of GPS and other systems, while bolstering the effectiveness of Golden Dome.

Background

Position, Navigation and Timing (PNT) is critically important to U.S. deterrence and warfighting, playing a key and growing role in maintaining US military superiority over its adversaries on the battlefield. Effective PNT has enabled the precision and lethality of conventional and special forces. U.S. national security is heavily reliant upon PNT. Indeed, the absence of such capabilities could mean the difference between success or defeat on the battlefield. This is also true in ensuring the success of the Golden Dome for America air and missile defense system that President Trump established by Executive Order 14186 on January 27, 2025. Yet, to date, weak, easily imitated and blocked signals from the Global Positioning System (GPS) system have been a prime weakness in a primary, often fundamental source of PNT for America's domestic infrastructure and expeditionary warfighting capability.

An effective Golden Dome system must be supported by a variety of space-based and terrestrial PNT sources with widely different failure modes to avoid the failure scenarios experienced by some U.S. systems in GPS denied environments. This is also true in ensuring Golden Dome's successful development, deployment and use as a deterrent and in a crisis when needed.

Moscow and Beijing are colluding to change the international system in ways favorable to their autocratic governance models, dominate regional spheres of influence, and extend their global influence and reach at the expense of the security of the United States, our allies, and international partners. The United States faces a renewed geopolitical competition and increasingly dangerous international security environment, primarily because of China, Russia and its partners[1] (such as North Korea and Iran). This Axis of Autocracies has built up an arsenal of ballistic missiles, cruise missiles, hypersonic delivery systems,[2] and unmanned aerial systems (UASs) capable of delivering nuclear or conventional weapons. Russia and Iran have used conventionally armed ballistic missiles, hypersonic systems and UASs in the Ukraine and Middle East with extensive effect on civilian and military targets.[3, 4, 5] In addition, North Korea has nuclear-armed intercontinental

1 Frank Gardner, "The race for the two miles-a-second super weapons that Putin says turn targets to dust", BBC, 21 August 2025 https://www.bbc.com/news/articles/cgeqj1q8gj4o

2 Shaan Shaikh, "China's Hypersonic Future", CSIS, December 12, 2021 https://missilethreat.csis.org/chinas-hypersonic-future/

3 Anastasiia Malenko, Tom Balmforth and Max Hunder, "Russia fired new ballistic missile at Ukraine, Putin says", Reuters, November 21, 2024 https://www.reuters.com/world/europe/russia-launches-intercontinental-ballistic-missile-attack-ukraine-kyiv-says-2024-11-21/

4 Alex Stezhensky, "Russia launches massive overnight assault on Ukraine using drones, ballistic and cruise missiles; air defenses shoot down 583 of 619 targets", MSN, September 20, 2025; https://www.msn.com/en-us/news/world/russia-launches-massive-overnight-assault-on-ukraine-using-drones-ballistic-and-cruise-missiles-air-defenses-shoot-down-583-of-619-targets/ar-AA1MXgrn

5 "Iran Strikes Israel: Updated Tracker of Every Iranian Ballistic Missile Fired at Israel", Haaretz, June 23, 2025 https://www.haaretz.com/israel-news/security-aviation/2025-06-23/ty-article-magazine/.premium/iran-strikes-israel-updated-tracker-of-every-iranian-ballistic-missile-fired-at-

ballistic missiles and is threatening their use on the US homeland and its allies in Asia and the Pacific.[6]

Based on this expanding threat to the US and its allies, President Trump directed, and Congress has funded, the "Golden Dome for America" initiative to defend the United States against ballistic, hypersonic, advanced cruise missiles, and other next-generation aerial attacks from various adversaries. Golden Dome includes accelerating the deployment of the Hypersonic and Ballistic Tracking Space Sensor layer, development and deployment of proliferated space-based interceptors capable of boost-phase interception, deployment of underlayer and terminal-phase intercept capabilities postured to defeat a countervalue attack, development and deployment of a custody layer of the Proliferated Warfighter Space Architecture, and development and deployment of capabilities to defeat missile attacks prior to launch and in the boost phase. For Golden Dome to be effective it needs to effectively detect, track and intercept its adversaries' systems using space based and terrestrial based capabilities.

This paper seeks to:

- Highlight current U.S. national policy related to PNT.
- Describe current and emerging Government and commercial PNT systems and capabilities, including global navigation satellite systems and terrestrial capabilities.
- Reference various current threats to U.S. PNT capabilities.
- Identify PNT requirements that underpin an effective Golden Dome system.
- Provide PNT-related recommendations for the development and deployment of the Golden Dome system over the next three years.

GPS/GNSS Policy and Capabilities

U.S. policy for decades has focused on PNT as an essential element of national and economic security. Department of Defense (now Department of War) Instruction 4650.08 on Positioning, Navigation, And Timing and Navigation Warfare (December 30, 2020) indicates "DoD will effectively employ NAVWAR capabilities to ensure a PNT advantage in support of military operations." This same Instruction also lays out roles and responsibilities within the Department of War (DoW) for managing national security PNT acquisitions and use of commercial and international PNT solutions. In Executive Orders issued in 2020 and 2021, President Trump further directed efforts to counter emerging PNT threats to U.S. security and economic critical infrastructure and foster a more resilient PNT capability.[7]

The Department of War developed, procured and currently operates the GPS constellation and associated systems through the U.S. Air Force (a responsibility assumed by the U.S, Space Force (USSF) upon its activation). The origins of military navigation and timing solutions began with the US Air Force 621B program, U.S. Navy's Timation program, and the Advanced Research Projects

israel/00000197-97f8-d5ef-a9bf-b7fedfc30000

6 Kim Tong-Hyung, "North Korea conducts its final ground test of a solid-fuel engine for long-range missiles", Associated Press, September 8, 2025 https://apnews.com/article/north-korea-rocket-engine-icbm-kim-jong-un-a72c2076435402c08ea57f47faac1d5f

7 Marc Berkowitz, "America's Asymmetric Vulnerability to Navigation Warfare", National Security Space Association Moorman Center for Space Studies, July 18, 2024; https://nssaspace.org/wp-content/uploads/2024/07/NAVWAR-FINAL.pdf

Agency's Transit navigation satellite system in the 1960's and 1970's and were initially used operationally by U.S. submarines for position knowledge.[8] Through successive testing, in 1995 what we now know as the current GPS constellation capability became fully operational.[9]

Today the GPS system is comprised of a satellite constellation containing a mixture of both older and newer spacecraft (6 GPS IIR, 7 IIR-M, 12 Block IIF, and 6 IIIs.[10]). The satellites are combined with control and user segments.[11] The GPS satellite system serves U.S. warfighters and commercial customers with user equipment deployed for both user segments. Given the orbital dynamics of the GPS satellite constellation in circular Medium Earth Orbit (MEO), at least six satellites are visible to users for use anywhere on the earth.[12] The constellation of 31 GPS satellites has been upgraded with IIR-M satellites (with atomic clocks) to harden the system against adversarial jamming methods to enable more resilient warfighter capabilities. Lockheed Martin is under contract to deploy 20 IIR-F GPS satellites with accuracy enhancements, more resilient satellite buses, and improved cybersecurity capabilities.[13]

The U.S. Space Force operates the current constellation of GPS satellites, the associated control segments, and provides common military User Equipment (UE) for the military services. Other military branches also deploy GPS UE for their unique applications and needs. Commercial entities provide UE for a variety of commercial applications including the aviation industry, agriculture, energy/utilities, transportation, and communications. It is important to note that what is actually deployed in weapons systems is a mix of SAASM receivers and M-Code receivers, and that the force will not be fully transitioned to M-Code for some time, as M-Code UE for certain weapons systems are not yet available. Why is this important - because some weapons systems are weaker due to using SAASM.

It should be noted that the Galileo global navigation satellite system (GNSS), deployed by the European Union through the European Space Agency, consists of 25 satellites and has the potential of providing additional PNT capabilities for the Department of War. Congress (as part of the 2018 National Defense Authorization Act) mandated that the Department of War promote the use of Galileo to enhance U.S. military PNT resiliency. However, the incorporation of Galileo into US military receivers remains a work in process.[14]

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8 See, for example, Brad Parkinson, et. al., "The Origins of GPS and the Pioneers Who Launched the System", GPS World, May 1, 2010, https://www.gpsworld.com/origins-gps-part-1/; Daniel Perry, "NRL Launched First Time-Based Navigation Satellite in 1967," May 31, 2023, https://www.nrl.navy.mil/Media/News/Article/3411925/nrl-launched-first-time-based-navigation-satellite-in-1967/; "Transit Satellite," Smithsonian, https://www.gps.gov/policy/docs/2021/; and "Transit Satellite: Space-based Navigation," Defense Advanced Research Projects Agency, https://www.darpa.mil/about-us/timeline/transit-satellite

9 U.S. Space Force, "Global Positioning System Fact Sheet," February 2023 https://media.defense.gov/2023/Feb/10/2003159890/-1/-1/1/GPS%20FACTSHEET.PDF

10 "The Global Positioning System: Current and Future Satellite Generations" https://www.gps.gov/systems/gps/space/

11 "The Global Positioning System," https://www.gps.gov/systems/gps; Global Positioning System Precise Positioning Service Performance Standard (Washington, D.C.: Department of Defense, 2007), https://www.gps.gov/technical/ps/2007-PPS-performance-standard.pdf; Global Positioning System (GPS) Civil Monitoring Performance Specification, 3rd ed., (Washington, D.C.: Department of Transportation, 2020), https://www.gps.gov/technical/ps/2020-civil-monitoring-performance-specification.pdf; and Defense Science Board Task Force, The Future of the Global Positioning System, (Washington, D.C.: Department of Defense, 2005), https://dsb.cto.mil/reports/2000s/ADA443573.pdf

12 "The Global Positioning System: Constellation Arrangement," https://www.gps.gov/systems/gps/space/

13 "GPS III/IIIF: The New Generation of Positioning, Navigation and Timing," Lockheed Martin, https://www.lockheedmartin.com/en-us/products/gps.html

14 Delay Continues for Effort to Add Galileo Signal to U.S. Military Receivers, November 16,2017, IG Inside GNSS, https://insidegnss.com/delay-continues-for-effort-to-add-galileo-signal-to-u-s-military-receivers/

LEO PNT

The Space Development Agency has plans under its Tranche 3 Transport Layer program (with the first 40 satellites to be deployed starting in 2028) to provide U.S. military operators with PNT signals through satellite deployments for situations where GPS is unavailable. The Proliferated Warfighter Space Architecture (PWSA) of communications and missile tracking satellites in low Earth orbit are designed to provide alternate PNT capability to ensure the constellations themselves can operate should GPS be denied by adversary jamming.

The satellite constellation planned by SDA is designed to provide an alternate and resilient PNT solution "based on using the laser links among the PWSA satellites, by "leveraging two-way time transfer (TWTT) and ranging from the Optical Intersatellite Satellite Links (OISL)".[15] According to SDA, "The Navigation Layer has three principal goals for the PWSA. First, PWSA will maintain continuity of operations and navigation warfare (NAVWAR) resilience. Second, PWSA will provide GNSS situational awareness (SA) data to the warfighter via the Network Established Beyond the Upper Limits of the Atmosphere (NEBULA) from potential GNSS terrestrial interference sources. Finally, PWSA will provide emerging military use-cases space-based PNT Services through both embedded TWTT and ranging within its space-to-ground communication links and from a dedicated PNT signal service. In this way, by maintaining continuity of operations in the absence of GPS, the PWSA provides alternative PNT to the warfighter."[16]

Using laser communications and associated ranging holds the potential for creating an alternate PNT signal with enhanced resilience to jamming and could provide the capability to pinpoint GPS jamming to the warfighter. In an abstract submitted for the Institute of Navigation Joint Navigation conference in June 2026, SDA officials provided additional details indicating PWSA will establish "resilient navigation capability using optical inter-satellite links (OISL), and optical space to ground links, and the Constellation, Speed, Time, and Range (COSTAR) orbit and clock determination algorithm that combines all PWSA Space Vehicle (SV) inputs to ensure a robust and resilient PNT solution. COSTAR operation on the OISL range and timing measurements are the key to the PWSA navigation independent of GPS signals-in-space. The design of the PWSA resilient navigation capability will create two vital space-based Positioning, Navigation, and Timing (PNT) services to the warfighter: Situational Awareness monitoring of terrestrial GPS RFI emitters, and Alternative PNT services."[17] Uncertainty exists as to the level of 2026 funding for this SDA effort as the U.S. Air Force and the U.S. Space Force are evaluating replacing the Tranche-3 satellites with purchasing commercial services from the SpaceX Starshield network through the Military Net (MILNET) program.[18]

Commercial companies such as TrustPoint and Xona Space Systems are making significant strides in offering PNT from satellites in Low Earth Orbit (LEO). TrustPoint is leveraging advanced C-Band capabilities for its LEO constellation to provide better accuracy, jamming and spoof

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15 Space Development Agency LinkedIn Post March 2025; https://www.linkedin.com/posts/space-development-agency_pwsa-gettoknowsda-sempercitius-activity-7313578581438128128-oXqI/

16 Space Development Agency LinkedIn Post March 2025; https://www.linkedin.com/posts/space-development-agency_pwsa-gettoknowsda-sempercitius-activity-7313578581438128128-oXqI/

17 Joint Navigation Conference June 2025; Session A11: Complementary PNT: PNT from LEO 3; Space Development Agency PNT Signal Service Early Demonstrations and Tranche 3 Operations *Edward Powers, SDA, The Aerospace Corporation; Gregory L. Weaver, SDA, JHU/APL; Shane David and David Wisniewski, SETA;* https://www.ion.org/jnc/abstracts.cfm?paperID=15697

18 Theresa Hitchens, "Uncertainty over satellite constellation means alt-GPS capability up in the air: Official -- The Space Development Agency's planned Navigation Layer, if it proceeds, would provide both the location of GPS jammers and alternate PNT signals"; Breaking Defense; September 23, 2025 https://breakingdefense.com/2025/09/uncertainty-over-satellite-constellation-means-alternate-gps-capability-up-in-the-air-as-well-official/

resiliency for national security, aviation, critical infrastructure, and automotive markets.[19] Xona Space Systems have launched their first commercial PNT satellites with the Pulsar-o satellite aboard the SpaceX Transporter-14 mission.[20] This is the first in a planned LEO constellation of PNT satellites designed to provide services across defense, construction, agriculture, mining, critical infrastructure, logistics, and automotive applications. Xona has designed their constellation to provide centimeter-level precision with encryption and modulation techniques resilient to jamming and spoofing.

GPS capabilities that were initially developed, deployed, and operated using U.S. Government funding to meet national security needs have evolved over time to satisfy economic and industry needs through commercial user equipment. Today, we are at a point in technology advancement, financial market resource availability, and economic benefit where commercial driven alternate space-based PNT has emerged as potential viable contributors to national security needs.

As LEO systems are matured and implemented, they will undoubtedly be an important part of PNT architecture.

Many terrestrial systems are already mature, and some have been implemented.

Terrestrial PNT

Terrestrial PNT capabilities hold the potential of enhancing US military capabilities and resiliency, especially in tracking and defeating UAS threats to metropolitan areas. This will be crucial to Golden Dome's role protecting metropolitan areas from unmanned aerial systems (UAS). These "Metro Golden Domes" must be equally responsive and will require access to a resilient PNT architecture as much as or more than other layers within the Golden Dome.

A wide variety of mature terrestrial PNT solutions are commercially available for government contract or purchase. We highlight two systems here offering immediate value to Golden Dome and the Metro Golden Dome.

Prior to GPS and for many decades, the U.S. used terrestrial based Loran solutions. These were based on a low-frequency, very high power, ground-based tower transmission systems, which can provide enhanced resilience for satellite based PNT. In 1997, Congress funded commercial Loran systems upgrades to develop enhanced Loran (eLoran) PNT services. Under the National Timing Resilience and Security Act of 2018, Congress directed the US Department of Transportation to develop a land based, resilient, alternative PNT solution as a back up to GPS. While the US Government has made attempts to fund eLoran development, and the Department of War is funding operation of three transmission sites in the northwest, a complete system has not yet been deployed to cover the continental US and Alaska.[21] Other countries, such as South Korea, Saudi Arabia, China, and Russia, have maintained Loran solutions, and the United Kingdom and France are deploying such solutions, to enhance the resilience of their nation's PNT capabilities.[22]

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19 Debra Werner, "TrustPoint wins SpaceWERX contract for alternative PNT", SpaceNews, August 21, 2024 https://spacenews.com/trustpoint-wins-spacewerx-contracts-for-alternative-pnt/

20 "Xona Space Systems has launched their Pulsar-o PNT satellite", Satnews, July 1, 2025 https://news.satnews.com/2025/07/01/xona-space-systems-has-launched-their-pulsar-0-pnt-satellite/

21 eLoran: Part of the solution to GNSS vulnerability, GPS World, By Matteo Luccio, November 3, 2021, https://www.gpsworld.com/eloran-part-of-the-solution-to-gnss-vulnerability/

22 Phasing Out GPS Reliance in U.S. Military Operations: An Imperative in the Face of Emerging Threats, By Carlo J.V. Caro, September 26, 2023,

One of the newest terrestrial PNT systems is based on television broadcast signals. The Broadcast Positioning System (BPS) was developed by the National Association of Broadcasters, using multiple frequencies, and existing broadcast infrastructure. The National Institute Standards and Technology have validated BPS as a precise timing source with the potential to provide location information as well.

The Department of Transportation continues to fund demonstration and development of both space-based and terrestrial complementary PNT systems for GPS.[23]

Current Threats to GPS/GNSS

Russia and China are currently developing or have deployed cyber, electronic warfare (EW), kinetic and directed energy, nuclear Anti-Satellite (ASAT) or counterspace weapons systems.[24] These adversarial capabilities provide a significant threat to U.S. and allied GPS/GNSS systems. As recently reported, Russia may be developing and planning to launch a nuclear-armed ASAT weapon.[25] Detonating a nuclear weapon in space poses a risk of degrading signal transmission operations or due to proximity destroying GPS/GNSS systems.[26]

China and Russia's allies in Iran and North Korea currently operate cyber, EW, and missile capabilities which can interfere with space assets and operations, including NAVWAR operations against GPS.[27] Russia has consistently and extensively interfered with GPS in its invasion of, and war on, Ukraine, interfering with unmanned and manned aerial vehicles and precision guided shells. This interference has included NATO allies in theater spoofing ships and air travel endangering.[28, 29] Russia has spoofed the position of U.K. and Netherland Naval ships, and endangered air traffic affecting Lithuania, Latvia, and Estonia.[30, 31, 32, 33]

RealClear Defense, https://www.realcleardefense.com/articles/2023/09/26/phasing_out_gps_reliance_in_us_military_operations_an_imperative_in_the_face_of_emerging_threats_981890.html

23 See for example https://sam.gov/opp/396f1f1e901a4155ace2263e3c70a588/view

24 Defense Intelligence Agency, Challenges to Security in Space (Washington, D.C.: Department of Defense, 2022), https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf; National Space Intelligence Center, Competing in Space (Wright Patterson, AFB, Ohio, 2018), https://media.defense.gov/2019/Jan/16/2002080326/-1/-1/0/190115-F-NV711-0001.JPG; National Space Intelligence Center, Competing in Space, 2nd ed., (Wright-Patterson AFB, Ohio, 2024), https://www.spoc.spaceforce.mil/Portals/4/Images/2_Space_Slicky_11x17_Web_View_reduced.pdf; Space Threat Assessment 2023 (Washington, D.C.: Center for Strategic and International Studies, 2023), https://www.csis.org/analysis/space-threat-assessment-2023; and Secure World Foundation, Global Counterspace Capabilities: An Open Source Assessment (Washington, D.C.: Secure World Foundation, 2024), https://swfound.org/media/207826/swf_global_counterspace_capabilities_2024.pdf

25 "Press Briefing by Press Secretary Karine Jean-Pierre and White House National Security Communications Advisor John Kirby," The White House, February 15, 2024, https://www.whitehouse.gov/briefing-room/press-briefings/2024/02/15/press-briefing-by-press-secretary-karine-jean-pierre-and-white-house-national-security-communications-advisor-john-kirby-3

26 Ibid.

27 Challenges to Security in Space; Competing in Space; Space Threat Assessment 2023; and Global Counterspace Capabilities: An Open Source Assessment.

28 "Cybersecurity Principles for Space Systems."

29 See, for example, Dana Goward, "Russia Ramps Up GPS Jamming Along with Troops at Ukraine Border," GPS World, April 21, 2021, https://www.gpsworld.com/russia-ramps-up-gps-jamming-along-with-troops-at-ukraine-border/

30 See, for example, H.I. Sutton, "Positions of Two NATO Ships Were Falsified Near Russian Black Sea Naval Base," U.S. Naval Institute News, June 21, 2021 https://news.usni.org/2021/06/21/positions-of-two-nato-ships-were-falsified-near-russian-black-sea-naval-base#:~:text=Positions%20of%20Two%20NATO%20Ships%20Were%20Falsified%20Near%20Russian%20Black%20Sea%20Naval%20Base,-By%3A%20H%20I%20Sutton&text=The%20tracking%20data%20of%20two,away%2C%20USNI%20News%20has%20learned

31 See, for example, Space Threat Assessment 2023.

32 Patrick Tucker, "Russia's GPS Meddling In the Baltic Sea Demands NATO Action, Sweden's Naval Chief Says" Defense One, April 9, 2024 https://www.defenseone.com/threats/2024/04/russias-gps-meddling-baltic-sea-demands-nato-action-swedens-naval-chief-says/395607/

33 "Russian GPS Jamming Threatens Air Disaster, Warn Baltic Ministers," Financial Times, April 28, 2024, https://www.ft.com/content/37776b16-0b92-4a23-9f90-199d45d955c3

Iran's recent war with Israel demonstrated both the importance of PNT capabilities and measures that will be deployed in war to deny GPS/GNSS services. GPS jamming incidents surged, impacting the navigation systems of nearly 1,000 vessels a day.[34] The International Civil Aviation Organization (ICAO) voiced grave concern in April 2025 during its meeting over North Korea's jamming of GPS.[35]

China has also been very active in conducting GPS interference activity in the Indo-Pacific theater. It has conducted EW operations against ground, maritime, and aerial platforms.[36] Both military and commercial aircraft have reported jamming, including Qantas airline operations in the South China Sea, Philippine Sea, and Indian Ocean.[37]

While a lower probability than malicious interference, the threat of accidental or natural events cannot be ignored. These include phenomena such as severe solar activity or the Kessler Syndrome (cascading space debris) interfering with or denying GPS signals on a temporary or long-term basis.

PNT Capabilities Underpinning an Effective Golden Dome System

Resilient PNT capabilities are essential to the Golden Dome's effectiveness in three vital underlying elements of the system: ISR and sensor platforms, precision-guided interceptors, and command and control (C2).

ISR and Sensor Platforms. Target acquisition and tracking, supporting the Golden Dome Hypersonic and Ballistic Tracking Space Sensor layer, are essential to munitions hitting their intended targets with precision thereby ensuring mission success in defending against ballistic missiles and hypersonic systems. Detecting and tracking adversarial systems in-flight can be challenging, and PNT solutions are critical to determining the "where" and "when"[38] vital in ensuring effective intercept information in all phases of potential adversarial attacks. According to Tom Karako and Masao Dahlgren, "Fire control-quality" tracks are those with the position and time accuracy sufficient for a missile defense system to generate an intercept solution."[39] Because the Golden Dome Space Sensor layer (detecting and tracking) must operate as an integrated and global space network of satellites, PNT provides vital synchronization necessary for effectively detecting and tracking adversary targets and communicating accurate information needed for precision guided intercept. In short, knowing where your detectors and trackers are in space in relationship with each other assists in generating highly accurate detection and targeting information necessary for ground- and space-based Golden Dome interceptors.

Precision-Guided Interceptors. PNT capabilities (celestial, terrestrial, and inertial references) will provide significant precision and lethality enhancements in Golden Dome

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34 Melissa B. Mahle, "GPS Jamming during Israel-Iran War Demonstrates Risks to Civilian Operations", Steptoe, July 2, 2025 https://www.steptoe.com/en/news-publications/stepwise-risk-outlook/gps-jamming-during-israel-iran-war-demonstrates-risks-to-civilian-operations.html

35 The Korea Times, UN aviation agency voices grave concerns over N. Korea's GPS signal jamming, by Yonhap, April 21, 2025 https://www.koreatimes.co.kr/foreignaffairs/northkorea/20250421/un-aviation-agency-voices-grave-concerns-over-n-koreas-gps-signal-jamming

36 Military and Security Developments in the People's Republic of China (Washington, D.C.: Department of Defense, 2023) https://media.defense.gov/2023/Oct/19/2003323409/-1/-1/1/2023-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF

37 See, for example, Maddie Saines, "Australian Aircraft GPS Receiver Jammed by Alleged Chinese Warships," GPS World, March 23, 2023 https://www.gpsworld.com/australian-aircrafts-gps-receiver-jammed-by-alleged-chinese-warships/

38 Bryan Benedict, "PNT – Answering the Where and When During Warfighting Missions", SES Space & Defense, February 26, 2025 https://sessd.com/gsr/pnt-answering-the-where-and-when-during-warfighting-missions/

39 Getting on Track: Space and Airborne Sensor for Hypersonic Missile Defense, CSIS, December 2023 https://csis-website-prod.s3.amazonaws.com/s3fs-public/2023-12/231218_Dahlgren_Getting_Track_0.pdf?VersionId=gyTyKePGJmFvnZmTgQY5._GidZ0jfGh4

interceptor capabilities. We now take for granted the videos we see of smart munitions utilizing the advancements in PNT to precisely engage and destroy fixed and moving targets. The importance of GPS/GNSS for Golden Dome is the enabling underlying technology to generate more precise Golden Dome interceptor systems (ground, air and space based). Golden Dome interceptors are operationally more effective through gathering and processing real-time data to assess the trajectory, speed, and potential impact of incoming cruise and ballistic missiles, UASs and hypersonic missiles. The interceptor's task is made significantly more effective by the underlying precise navigation and timing solutions. Timing as part of interceptor systems is crucial in providing the essential synchronization that ensures elements of the Golden Dome interceptors operate efficiently and effectively. This is particularly important for communications associated with missile defense systems and their interceptors. Simply put – it is critical for the interceptors to know more precisely where and when the target will be for a successful intercept.[40]

Command and Control Systems. In the complex and dynamic environment of missile defense, timing is the underlying foundation that enables nearly every operational aspect of Golden Dome's effectiveness. From coordinating large-scale intercepts (by delivering precision-guided interceptors) to ensuring secure communication, timing serves as the invisible thread that weaves disparate systems and elements into a cohesive missile defense command and control capability. The accuracy and availability and reliability of GPS/GNSS systems (position and timing information) as well as upcoming PNT backup systems to increase PNT resilience directly impact the operational effectiveness of Golden Dome command and control systems. The principal role of GPS/GNSS in Golden Dome command and control is as a shared resource critical in establishing near perfect Situation Awareness to enhance Command and Control ability to optimize resources in defeating adversarial attack systems. GPS/GNSS generated PNT provides a common and consistent coordinate reference for Golden Dome defensive planning and operations.

The importance of timing is evident across Golden Dome air, land, sea and space domains. Accurate GPS/GNSS generated timing enables Golden Dome's command and control systems to securely coordinate across vast areas, generating seamless execution of complex intercept-missions. Without precise and resilient, verifiable timing information, Golden Dome command and control communication networks could fail, compromising the transmission of critical information needed for successful defensive missions. Golden Dome command and control is reliant on nanosecond-level timing accuracy to deliver precise positioning data and while avoiding timing errors that could result in positional inaccuracies that will jeopardize mission outcomes.

In addition to the role of GPS/GNSS in Golden Dome defense's communications and navigation, timing is crucial for command-and-control systems optimizing overall coordinated system effectiveness. Precision-guided Golden Dome interceptors and associated sensor systems for detecting and targeting will be heavily dependent upon command-and-control systems synchronizing timing and calculating trajectories to deliver robust defense against incoming targets. Disruptions in timing can compromise these systems, resulting in missed targets or unintended collateral damage.

40 Missile Defense Multi-Constellation PNT: Integrating Celestial, Terrestrial, and Inertial Sources, Diverse Daily; https://diversedaily.com/missile-defense-multi-constellation-pnt-integrating-celestial-terrestrial-and-inertial-sources/

Recommendations

The Golden Dome system architects must factor in the strengths and vulnerabilities of existing PNT systems (celestial and terrestrial) and conduct a rapid gap analysis on what improvements are critical in meeting Golden Dome system requirements. The gap analysis should focus on GPS/GNSS resiliency and capability improvement to meet the overall Golden Dome system performance requirement to include ISR sensors for rapid detection, tracking and targeting, improvements to precision-guided interceptors, and command and control systems.

A PNT improvement budget should be established to rapidly address gaps in capabilities needed to meet Golden Dome system effectiveness requirements with the goal of deploying the improvements within the next three years (this also would satisfy the mandate in Space Policy Directive 7, issued in the first Trump Administration[41]). Given the essential importance of PNT to the Golden Dome system, Golden Dome for America Direct Reporting Program Manager (GDA DRPM) General Michael Guetlein should designate a Golden Dome PNT lead with identified supporting DoW service elements to ensure that PNT system improvements are executed to meet overall Golden Dome system performance needs and timelines.

Initiate an integration management activity that addresses the challenge of integrating and timely testing of counter-PNT, and develop rapid, feasible PNT augmentation that generates resilient systems likely to become part of Golden Dome. A major lesson can be learned from counter UAS (cUAS), critical infrastructure, and integrated air and missile defense (IAMD). Integration across systems that Golden Dome is dependent upon, systems that protect Golden Dome, and Golden Dome specific systems are essential to avoid electronic fratricide, system interference, and degraded system performance. Each of these systems is dependent upon common PNT frequencies, signals, and enablers that Golden Dome will also seek to defeat in an adversary system. The adversary will also be employing counter-PNT systems, and those adversary systems must be thwarted.

User equipment is always thought about too late. This results in very high integration costs across the weapon systems when changes occur. Consequently, the DoW leadership should prioritize and modernize Golden Dome system components to Assured PNT, M-Code GPS, and Controlled-Reception Pattern Antennas (CRPA) as soon as possible. Begin with a PNT capability inventory and dependency analysis, especially on time dependencies across Golden Dome system components and large distances (e.g. distributed time sync dependencies). The Army's Direct Reporting Program Manager for PNT conducted this same inventory and dependency analysis across all Army weapons systems, prioritized by kill chain and operational plans. This enabled the Army to decisively address gaps and vulnerabilities and prioritize the migration to Assured PNT, M-Code GPS and controlled-reception pattern antennas (CRPA).

Due to the urgency of the mission as directed by the President for the Golden Dome system, innovative PNT development and acquisition strategies (such as those employed by the Space Development Agency) should be expanded and should include adoption of commercial services and best practices to leverage financial markets and associated innovation. A mixture of bespoke national security PNT system improvements combined with commercial innovation and suppliers can enable rapid and resilient improvements in the timeline needed for Golden Dome deployments.

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41 The White House, Memorandum on Space Policy Directive 7, President J. Donald Trump, January 15, 2021, https://trumpwhitehouse.archives.gov/presidential-actions/memorandum-space-policy-directive-7/

Finally, Congress should request a report from the Office of the Secretary of War on Golden Dome's PNT improvement plan and the funding needed to rapidly implement the most promising next generation PNT resilient solutions, consistent with the urgency of the vital homeland defense mission.

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The views expressed herein are solely those of the authors and do not reflect the views of the Association or its member companies.

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Glossary

ASAT – Anti-satellite weapons that destroy or disable satellites

Boost phase – The initial stage of a ballistic missile's flight where its engines are firing to provide thrust and gain velocity

CRPA – Controlled Reception Pattern Antenna

cUAS – Counter Unmanned Ariel Systems

Custody layer – Government owned or controlled satellite constellations with multiple sensing modalities

GNSS – Global Navigation Satellite Services

GPS – Global Positioning System

Hypersonic – Traveling five times the speed of sound (Mach 5) or faster

IAMD – Integrated air and missile defense

ISR – Intelligence, Surveillance, and Reconnaissance

LEO – Low Earth Orbit, the region of space below 2,000km. Most communication satellites are in LEO.

LEO PNT – Low Earth Orbit Positioning, Navigation, and Timing

M-Code – An encrypted GPS signal for military users that enhances security and resistance to jamming and spoofing

MEO – Medium Earth Orbit or the region of space between 2,000km and 35,786km – GPS and other GNSS are in MEO

MILNET – A developing low-Earth orbit (LEO) satellite constellation for global communications services.

NATO – North Atlantic Treaty Organization

NEBULA – A network that facilitates space-to-space and space-to-ground communications.

PNT – Positioning, Navigation, and Timing

Proliferated Space – A military strategy of using a larger number of smaller, less expensive satellites, often in Low Earth Orbit, to create a more distributed and resilient architecture.

SAASM – Selective Availability Anti-Spoofing Module, is a military technology used in GPS receivers to protect against spoofing and jamming.

SV – Space Vehicle

Terminal Phase – the final stage of a missile's flight, beginning when its warhead(s) reenter the Earth's atmosphere and ending at impact or detonation

UAS – Uncrewed aerial system

UE – User equipment

UK – United Kingdom

Underlayer phase – The part of a missile's flight that can be countered by shorter range missiles that are not part of the primary defense.