Positioning, Navigation, and Timing Strategic Plan

U.S. Department of Transportation

December 2024

Message from the Secretary of Transportation

As history tells us – from the star-charting techniques used by 18th century explorers to the ride-sharing apps of the 21st century – understanding one's location and navigation is critical to safe, efficient travel.

Over the last century, the United States has developed and refined navigation and timing systems that helped guide service members during World War II, launched satellites into space starting in the 1960s, and paved the way for Global Positioning System (GPS) technology as we know it today. For more than three decades, the Department of Transportation (DOT) has led the civilian use of GPS. And as GPS developed, DOT created positioning, navigation, and timing (PNT) tools to help support the rapid advancement of our nation's transportation and consumer technologies.

Today, PNT is part of our day-to-day lives, and transportation is closely entwined with other civil systems and uses of PNT. Travelers can book ride-shares, e-scooters and bicycles, buses, or commuter rail on demand because the financial industry can process these transactions in near-real-time—incorporating PNT to apply time stamps, identify location and position information for pick-ups and drop-offs, or calculate payment based on distances. The agricultural industry uses PNT for precision farming and to transport their harvests to where consumers can access the products they need. PNT tools guide people safely in boating, hiking, skiing, and other recreational activities, and to provide important rescue services when people need help. And there is great potential for drones, which rely upon PNT, to inspect bridges, care for crops, or deliver medicine to homebound seniors.

Some of the most important new frontiers of our time are to be found in the transportation sector, and almost all of them depend in some way on PNT. We are witnessing the rise of electric and autonomous vehicles, the widespread adoption of recreational and commercial drones, renewed attention to cybersecurity vulnerabilities in our infrastructure, increasingly routine commercial space travel, and perhaps most urgently, the high-stakes race to dramatically reduce transportation's impact on our climate before it's too late. In our lifetimes, we could see truly smart cities – built on connected technology that requires PNT – where cars, buses, and infrastructure all communicate with each other to plot safer routes and use less energy. We could even see regular suborbital spaceflight that transforms international travel and brings the world even closer together.

Good governance and sound policies are essential in driving existing and emerging PNT technology forward. Working together, public investments help create the infrastructure needed for private inventions and operations to reach their fullest potential.

In this new Department of Transportation PNT Strategic Plan, the Department accounts for what has come before, lessons learned, and successes as a means of evolving key technologies such as PNT – using our policy tools to support private sector and academic innovations, and making sure the technologies and innovations deliver safety, security, resilience, convenience, and economic opportunity for the American people. At the heart of these solutions is the ability to receive reliable, trustworthy, and consistent PNT. Our PNT team is focused on delivering this important use for the nation, as described in this DOT Strategic PNT Plan.

Supporting, fostering, and safeguarding the work of transportation innovation is vital, and that includes advancing PNT capabilities in a safe, secure, protected, and resilient manner, supporting the knowledgeable and intentional uses of the right forms of PNT with civil users, protecting the spectrum through which PNT is communicated, and continuing the civil PNT leadership—both here at home and across the world.

These efforts come at an exceptionally important time in the story of American transportation. The decade ahead will bring countless transformative changes in how people and goods move around the country and around the world. And the Department of Transportation will be there, working with innovators and those who can help advance PNT for our Nation and to make sure these developments benefit the American people.

Secretary Pete Buttigieg

Message from the Principal Deputy Assistant Secretary for Research and Technology and Chief Science Officer

The Office of the Assistant Secretary for Research and Technology (OST-R) works at the dynamic intersection of research and development (R&D) of new and emerging transportation technologies, data systems, and policy. OST-R is responsible for organizing the Department's technology activities into a forward-looking strategy as identified in the DOT Research, Development & Technology (RD&T) Strategic Plan, developed in conjunction with the DOT Operating Administrations representing all modes of transportation. OST-R engages in complex issues related to enabling technologies, including artificial intelligence, highly automated safety systems, and Positioning, Navigation, and Timing (PNT) which are essential for the future of transportation.

PNT is one of the critical enabling capabilities for the safe and efficient shared use of the national transportation system by the traveling public and the freight community; and for all users of the roads, rails, waterways, and airspace within the United States, including vulnerable road users.

In addition to transportation applications, PNT services are foundational and essential throughout many, if not all, sectors of the economy such as surveying, the financial sector, machine control, precision agriculture, science missions, and space applications. Critical infrastructure sectors such as communications, banking, the electric grid, and dams also rely on the resilience of PNT technologies. Both a robust set of PNT services AND the adoption of these services by critical infrastructure operators is necessary to our economy, our well-being, and ultimately our safety.

However, threats to the systems, technologies, and organizations that deliver PNT services are increasing daily, including to the GPS which relies on signals broadcast from distant satellites with a low signal strength at the receiver, making the service vulnerable to intentional and unintentional disruptions. Recent Federal policies have created the guidance and foundation necessary to invest and participate in advancing the research to create greater resiliency and security for PNT capabilities. The Department's PNT efforts and commitment come at a pivotal point in history, especially for transportation, as we plan for and look to a future based on connectivity, automation, artificial intelligence, and the advancement of new technologies such as quantum capabilities that can harness the properties of individual atoms to better and more reliably navigate and communicate. In order to realize the benefits of a resilient, innovative, and more robust system, our priority is to ensure that safe and reliable PNT services are available and adopted into applications for an ever-growing community of users.

As the PNT Civil Lead, DOT will continue to actively advocate on behalf of the civil user community and champion initiatives to protect and modernize PNT capabilities in partnership with Federal partners, as well as defend and advocate for these vital services. Given the use of PNT throughout the transportation systems sector, DOT embraces our civil leadership role in helping to ensure accurate and reliable sources of PNT for civil uses throughout the Nation, as well as ensuring these and complementary systems are available to meet current and emerging applications and supporting infrastructures.

Using this PNT Strategic Plan as a basis, the Department will lean forward into research, technologies, and investments that push the boundary of what’s possible – innovations that help us achieve our goals, grow our economy, unlock creativity and entrepreneurship to meet current and future needs for PNT. Working through our partnerships, the Department will ensure we are implementing a National PNT Architecture that will shape our future for generations.

Robert C. Hampshire, PhD.

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INTRODUCTION

Positioning, Navigation, and Timing (PNT) services are vital to critical infrastructure and enable safe, secure, and efficient use of transportation systems across the Nation by Federal, State, commercial, and private entities within the United States and its Tribal Lands and Territories. PNT services provide indispensable data and information to guide the Nation's air and maritime supply chains and freight logistics; support efficient operations and crash prevention on our roadways; facilitate safe, shared road usage among vehicles and other road users; and help to ensure safe, secure, and efficient aviation operations.

PNT services enable our Nation's robust economy and commerce. These services are a foundational element in the technologies and operations used in synchronization of telecommunications, mobile Internet of Things (IoT), power generation and transmission, financial transactions, precision agriculture, surveying, advanced construction technologies, mining and exploration for natural resources, earthquake detection, space missions, scientific applications, and other important civil uses.

Given the growing reliance on PNT within civil applications, it is imperative that civil PNT users have uninterrupted PNT services. This imperative is reflected in the policy of the U.S. Government's Executive Order (EO) 13905 that seeks "to ensure that disruption or manipulation of PNT services does not undermine the reliable and efficient functioning of its critical infrastructure...and [to] ensure critical infrastructure can withstand disruption or manipulation of PNT services." [1] As discussed throughout this DOT PNT Strategic Plan, adoption and use of appropriate Complementary PNT (CPNT) services by critical infrastructure owners, operators, and users ensures the Nation's critical infrastructure will have continuous and reliable PNT services.

1 EO 13905 can be found at https://www.federalregister.gov/documents/2020/02/18/2020-03337/strengthening-national-resilience-through-responsible-use-of-positioning-navigation-and-timing.

PNT services are critical to the functioning of our entire digital world. Without accurate, available, trustable, and secure PNT services, our economy, quality of life, and safety would be significantly challenged and many aspects of what we have come to expect from life in the 21st century would cease. Important benefits in safety-critical applications, mobility, environment, and cybersecurity would be lost, and both the financial and environmental costs of living without these technologies, including recovering from the loss, would quickly become unsustainable.

As the lead U.S. Government (USG) Civil Department for PNT, the DOT embraces our leadership role and actively partners with Federal Departments and Agencies to analyze and coordinate on systems requirements and policy. DOT presents this PNT Strategic Plan as a means to focus national attention on this critical subject to ensure our Nation has precise, robust, and resilient sources of PNT to support both current and emerging applications. This PNT Strategic Plan offers five key interrelated strategies for improving resilience and sustaining today's PNT services, addressing existing and emerging challenges, and creating an achievable path for the future by:

- Advancing technologies, systems, and a National PNT Architecture that enables and delivers the Nation's PNT services and capabilities.
- Building in PNT resiliency through improvement of existing systems and supporting a system-of-systems approach.
- Addressing the cybersecurity risks and challenges to PNT systems and applications that exist today and new threats as they emerge.
- Ensuring the availability of spectrum required for PNT services and protecting PNT services against harmful interference.
- Leading continued civil PNT coordination for the Nation and within the international transportation community.

PURPOSE OF THE DOT PNT STRATEGIC PLAN

The purpose of the DOT PNT Strategic Plan is to establish a path to advance, protect, and coordinate services for civil PNT uses with Federal Departments and Agencies, interface with industry stakeholders and users, and collaborate with international partners. This strategic plan is designed to offer a longer-term vision, albeit one that also supports near-term goals and objectives. By developing and publishing this DOT PNT Strategic Plan (hereinafter referred to as "the PNT Plan"), DOT is working to fulfill the following goals:

- Advance and evolve PNT services, data integrity, and resiliency to meet the needs of current and future civil applications.
  - This goal includes promoting the responsible use of PNT services in civil and commercial sectors at the Federal, State, and local levels, including the utilization of multiple and diverse CPNT technologies or approaches for national critical functions.
- Emphasize that U.S.-based PNT use cases have worldwide geographical breadth and regularly cross borders—e.g., transportation, commerce, security, finance, scientific applications and innovations, and others; and emphasize the importance of addressing challenges facing the technologies and systems that deliver PNT services with a focus on strengthening resiliency, robustness, efficiency, and cybersecurity.
- Underscore the importance of PNT and ensure alignment with the Fiscal Year (FY) 2022-2026 DOT Strategic Plan,[2] as well as the goals and objectives in the DOT's Research, Development, and Technology (RD&T) Strategic Plan;[3] while also coordinating alignment of PNT priorities across Federal Civil Departments and Agencies.
- Offer the broader stakeholder community and future Administrations a better understanding of DOT's Civil PNT Leadership role and the challenges facing PNT.
- Act as a guide for the future of what is required to ensure resilient and cybersecure PNT for national critical infrastructure, as well as coordination among government agencies and with private sector and academic partners.

2 https://www.transportation.gov/dot-strategic-plan
3 https://www.transportation.gov/rdtstrategicplan

PNT CHALLENGES

As the PNT Civil Lead, DOT must address both current and future challenges that include:

- Increasing occurrences of Global Positioning System (GPS) jamming and spoofing and the growing need to be able to quickly detect and mitigate interference.
- Fostering implementation of PNT cybersecurity awareness and protections as new forms of cyberattacks continue to emerge.
- Promoting "responsible use" and "risk-based decision-making" by PNT users, especially for critical infrastructure operations.
- Increasing dependency on precision timing.
- Ensuring the availability of spectrum for resilient PNT services, including alternative/complementary sources.[4]
- Maintaining vigilance of ever-changing global conditions to provide leadership with:
  - Standards and international partner agreements
  - Coordination of PNT use internationally
  - PNT skills, education, and training.

PNT PRIORITIES

DOT, along with our USG interagency partners, recognize the importance of delivering the next generation of PNT by:

- Anticipating and accounting for future needs, including maintenance and evolution of the National PNT Architecture with modernization of GPS in partnership with the Department of Defense as the cornerstone of that architecture.
- Assessing PNT technologies' capabilities and vulnerabilities, and promoting diversity in systems that can provide accurate, reliable, and resilient PNT services by enhancing existing systems including new technologies that can serve a broad range of civil PNT needs.
- Protecting and toughening current systems and creating standards and specifications to design these capabilities into future systems, including protecting spectrum that delivers PNT signals.
- Creating robust interference detection and location systems.
- Coordinating with a broad range of Federal agencies that represent critical infrastructure owners and operators, civil PNT stakeholders, and PNT users within the U.S. and across jurisdictional borders; to help document and communicate stakeholder and market needs.

4 For the purposes of this Plan, CPNT includes PNT technologies that either complement GPS or offer alternatives to GPS.

DEVELOPMENT OF THIS PLAN

The U.S. Department of Transportation's Office of the Assistant Secretary for Research and Technology (OST-R), PNT and Spectrum Management Program, and the John A. Volpe National Transportation Systems Center (Volpe Center) developed this plan with input from USG Departments and Agencies that are members of the DOT Extended PNT Working Group, and with stakeholder input gathered during a public listening session.

PNT STRATEGIC PLAN STRUCTURE

The PNT Plan is organized into five sections:

1. An introduction that describes development of the PNT Plan and its purpose.
2. A discussion on the importance of PNT services to the Nation and DOT's role as the civil PNT policy lead; including a description of how the PNT Plan's strategic goals align with the DOT's Strategic Plan and the DOT's RD&T Strategic Plan and goals.
3. A description of the five DOT PNT strategic goals and initiatives with a discussion of vision, implementation activities (in partnership with the Department of Defense (DOD), the Department of Homeland Security (DHS), and other Federal Agencies) and desired outcomes for each goal.
4. A conclusion.
5. Appendix A: Acronyms.

As DOT's Strategic Plan and RD&T Strategic Plan illustrate, the Nation is undergoing significant transitions that will alter:

- How we travel, with growth in automation, on-demand transport, and multimodal connections that will deliver greater accessibility and broader equity in services;
- Vehicles that transport us, introducing new forms such as electric Vertical Take-off and Landing (eVTOL) and electric vehicles that feed and are fed by a ubiquitous electric grid; and
- How goods are delivered, for instance by drones, uncrewed ground vehicles, or sidewalk robots.

IMPORTANCE OF PNT SERVICES TO THE NATION

The U.S. Government provides GPS as a robust and reliable PNT service that is open, stable, accurate, and free to access. This has resulted in the incorporation of PNT data and capabilities into numerous applications, systems, services, and infrastructure sectors. Beyond the familiar use of mapping and navigation functions, PNT systems "have become a largely invisible utility for technology and infrastructure, including the electrical power grid, communications infrastructure and mobile devices, all modes of transportation, banking and finance, precision agriculture, weather forecasting, and emergency response."

- White House, National Research and Development Plan for Positioning, Navigation, and Timing Resilience, August 2021[5]

5 See **https://www.whitehouse.gov/wp-content/uploads/2021/08/Position_Navigation_Timing_RD_Plan-August-2021.pdf**.

As stated in the DOT Strategic Plan FY 2022–2026, safety is the Department's top priority. PNT services must be accurate, reliable, available, and trustworthy to safely and effectively support current and emerging transportation services, applications, and supporting infrastructures (including geodesy—the science of measuring and understanding three fundamental properties of the Earth, including its geometric shape, its orientation in space, and its gravity field—as well as the changes of these properties with time).

PNT is a combination of three distinct but interrelated functions of any system, network, or capability that provides a reference to calculate or augment the calculation of longitude, latitude, altitude, velocity, or transmission of time or frequency data, or any combination thereof in support of positioning, navigation, or timing.

POSITIONING

The ability to determine one's location and orientation accurately and precisely in two dimensions (or three dimensions when required), referenced to a standard geodetic system (such as World Geodetic System 1984, or WGS84).

NAVIGATION

The ability to determine current and desired position (relative or absolute) and apply corrections to course, orientation, and speed to attain a desired position anywhere around the world, from sub-surface to surface and from surface to space.

TIMING

The ability to acquire and maintain accurate and precise time from a standard (Coordinated Universal Time, or UTC), anywhere in the world and within user-defined timeliness parameters. Timing also includes time transfer.

PNT services and applications support many aspects of American commerce and affect the daily lives of every American. To ensure these service needs are met, the USG engages with both the public and private sectors to identify and promote the responsible use of PNT services; understand current and emerging needs; translate needs into requirements; and evolve, protect, toughen, augment, and adopt PNT capabilities to serve those needs.

The transportation sector is one of the largest users of civil PNT services. PNT services enable the precise time transfer required for communication networks and crash avoidance technologies; improve satellite orbit determination and aid space situational and space domain awareness efforts; improve the accuracy of oil and natural gas pipeline in-line-inspection equipment; enable autonomous and semi-autonomous vehicles; and help protect national security by improving the logistics and operational effectiveness of the military.

In particular, aviation systems rely significantly upon the consistency and integrity of PNT signals throughout all phases of a flight—from preflight and takeoff to approach and landing. The rail industry relies on PNT for its shared track and positive train control (PTC) systems.[6] PNT is crucial in the maritime industry and is used by mapping systems to avoid grounding, beacon systems to track ships and avoid accidents, and sensors for clearance under bridges. As communications and automation technologies are incorporated into roadway vehicles, PNT becomes increasingly important as a means of crash prevention, as well as a means of increased mobility and decreased environmental impacts.

6 Shared track systems allow freight rail and passenger rail operations on the same trackage.

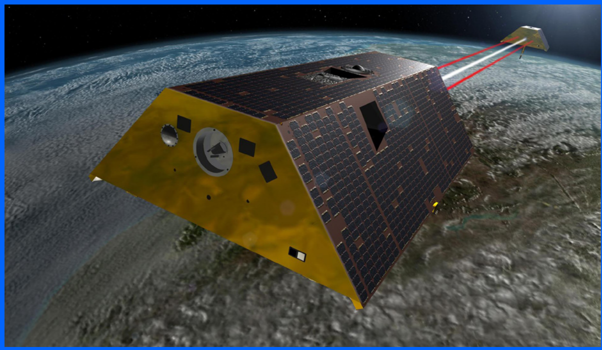
PNT ROLE IN TRANSPORTATION

PNT services enable the precise time transfer required for communication networks and crash avoidance technologies; improve satellite orbit determination and aid space situational and space domain awareness efforts; improve the accuracy of oil and natural gas pipeline in-line-inspection equipment; enable autonomous and semi-autonomous vehicles; and help protect national security by improving the logistics and operational effectiveness of the military.

Table 1:
Examples of PNT in transportation services, applications, and supporting infrastructure

AVIATION uses PNT for communications navigation, surveillance, automation, and weather services to support taxiing, takeoff, climb, enroute, descent, approach, and landing. New forms of automated aviation and advanced air mobility (AAM) are emerging and require accurate PNT data for surface operations and navigating the airspace.

SPACE TRANSPORTATION incorporates PNT in navigation for high precision orbit determination, altitude determination, vehicle launch controls, radar tracking, autonomous flight termination, and constellation controls. Among other systems, PNT supports timing solutions for spacecraft atomic clocks and precision time GPS receivers. Other uses of PNT include formation flying that requires minimal intervention from ground crews or virtual platforms for automatic "station keeping" and relative position services for advanced science tracking maneuvers such as interferometry.



COLLISION AVOIDANCE TECHNOLOGIES use PNT to address crash prevention between vehicles and pedestrians, bicyclists, scooters, wheelchairs, and other vulnerable road users. As vehicles are evolving into "computers on wheels" they are becoming more highly dependent upon accurate and uniform timing data. New applications for vulnerable road users require accurate positioning and, when linked to traffic signal systems or vehicle-based prediction systems, utilize timing data to prevent crashes.

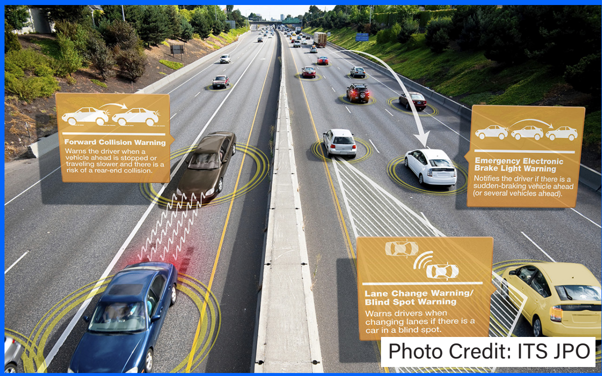


Photo Credit: ITS JPO

All images are Adobe Stock unless noted differently

VEHICLE AND INFRASTRUCTURE COMMUNICATIONS rely upon PNT for interoperable connectivity through vehicle-to-everything (V2X) communications that enable new navigation applications, urban canyon and tunnel navigation, and digital infrastructure. PNT technologies are increasingly deployed for safe navigation through complex intersections. Cooperative, interoperable driving automation depends on precise and trusted positioning and timing to prevent crashes and allow vehicles and other road users to "interweave" through traffic.


Photo Credit: ITS JPO

MARITIME SHIPBOARD SYSTEMS incorporate PNT into mission-critical systems for capabilities such as under keep clearance (UKC) monitoring, electronic chart display information systems (ECDIS), Automated Identification Systems (AIS), and dynamic positioning and station keeping. PNT data is also critical as a navigation aid to prevent collisions with other ships and with infrastructure, such as bridge strikes.

RAIL employs PNT for shared track and PTC operations. Other uses for PNT include railroad operations and infrastructure development and maintenance which rely upon a wide range of locational and timing needs including surveying and mapping, track defect location, weather forecasting and high-capacity communications. PNT data also support bridge and tectonic monitoring for rail bridge safety.

TRANSIT puts PNT into use for services such as precision docking of buses, wayfinding in kiosks used by transit riders, or use of right-of-way for buses, among other uses. Emerging micro mobility services use PNT to track location of vehicles, both in use and when not in use as well as to track speed and distance, the latter being useful for dynamic fare pricing.


Photo Credit: ITS JPO

PIPELINES use PNT for in-line-inspection equipment, pipeline mapping, and pipeline management and monitoring systems which often rely upon GPS time signals.

COMMERCIAL FREIGHT LOGISTICS rely upon PNT for safety and enforcement capabilities and incorporate PNT into weigh-in-motion; new, emerging micro-freight solutions; and emerging, automated driving and platooning applications. The worldwide supply chain is dependent upon PNT as well.


Photo Credit: ITS JPO

PRECISION DRONE LOGISTICS uses PNT for route planning, package delivery arrival estimations, crash avoidance, and automation. PNT data is essential when using drones for transporting cargo, in particular to transport dangerous goods between land-based and offshore facilities and vessels, for instance.

CONSUMER UTILITIES include civil services such as banking and financial markets, water systems, energy systems and electrical grids, telecommunications, and the IoT. Energy systems use PNT for energy delivery and electric grid operations. Financial systems rely upon the accurate time stamp capability when electronically transferring money or financial assets around the world.

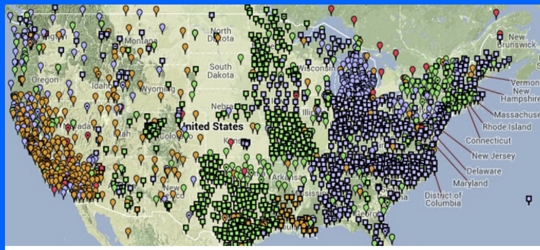
The stringent PNT requirements for transportation—and safety-critical systems in particular—flow down and apply to meeting requirements for a broad range of civil and commercial PNT uses—everything from telecommunications to financial transactions to precision agriculture to a wide range of scientific and natural resource enterprises. Examples of civil services and applications that rely upon PNT services are described in Table 2.

Table 2: Role of PNT in non-transportation civil use services and applications

PRECISION AGRICULTURE uses PNT to assess field conditions and for resource management and supports tractor guidance systems. PNT data allows for site-specific farming, farm planning, field mapping, soil sampling, crop scouting, variable rate applications, and yield mapping which enables farmers to work during low visibility field conditions such as rain, dust, fog, and darkness.

CONSTRUCTION AND MINING incorporate PNT in equipment used for locating assets, building and equipment diagnostics monitoring and maintenance, and worker safety. PNT data is essential in such services as tunnel boring, open pit mining, or earth movement.

PUBLIC SAFETY AND EMERGENCY RESPONSE SERVICES use PNT in disaster relief, earthquake early detection, and search and rescue operations. Positioning data is essential to identifying the location where emergency services are needed, and navigation aids in safe transport to the location as well as to hospitals and other services.



Credit: NOAA National Geodetic Survey, print out of ESRI GIS System

NATIONAL SPATIAL REFERENCE SYSTEM (NSRS) incorporates PNT into surveying, wetlands delineation, or urban planning. Mapping (including high-definition maps) relies upon PNT for accurate navigation. NSRS, a consistent coordinate system for latitude, longitude, height, scale, gravity, and orientation throughout the U.S., manages services such as the Continuously Operating Reference Systems (CORS) used by surveyors and other high-precision positioning users.

SURVEYING was one of the first civil users of high-precision PNT and uses PNT data in combination with other essential services such as geodesy and mapping to support mining and resource extraction and, in combination with remote sensing, for sustaining natural resources. This includes such applications as monitoring shoreline changes (which supports flood mapping), charting wildlife habitats, tracking emissions, or fire protection and suppression.

OUTDOOR RECREATION is a $500B+ market, as calculated by the Bureau of Economic Analysis.[7] PNT is essential for recreational boating nearby or outside of shipping lanes, trail mapping, and fitness tracking, among other uses.

SCIENTIFIC AND COMMERCIAL APPLICATIONS use PNT data to support important scientific investigations using a network of thousands of GPS/Global Navigation Satellite Systems (GNSS) stations to measure tectonic, volcanic, and land surface deformation with sub-millimeter per year precision. PNT data also support monitoring of natural threats such as adverse space weather including geomagnetic and ionospheric storms and scintillations and solar flares.

SMART CITIES are areas in which transportation and many other civil applications converge and combine. PNT is critical for services such as ensuring public safety can respond to incidents safely and emergency vehicles reach hospitals quickly, banking and financial transactions support seamless payments throughout smart communities, or energy and water demand reaches customers as needed.

WEATHER FORECASTING relies on PNT for weather prediction, charting extreme weather patterns, or tracking sea ice and rising water levels. In support of aviation, PNT data is an essential feature of weather instrumentation that uses sensors to measure visibility and present weather, temperature, relative humidity, pressure, and wind speed to inform safe aviation operations.

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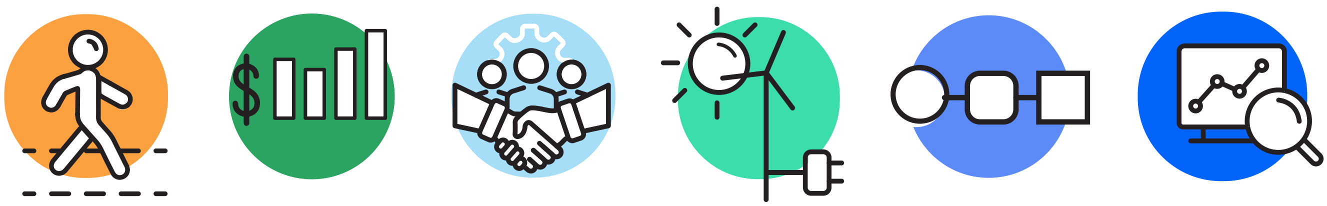
7 See **https://www.bea.gov/data/special-topics/outdoor-recreation#:~:text=The%20value%20added%20of%20the.**

THE U.S. DEPARTMENT OF TRANSPORTATION STRATEGIC GOALS

DOT's mission is "To deliver the world's leading transportation system, serving the American people and economy through the safe, efficient, sustainable, and equitable movement of people and goods."

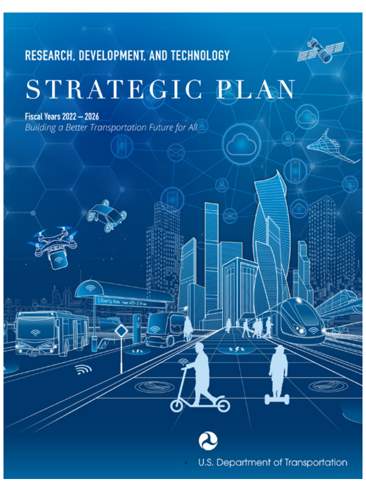
STRATEGIC GOALS



SAFETY | ECONOMIC STRENGTH AND GLOBAL COMPETITIVENESS | EQUITY | CLIMATE AND SUSTAINABILITY | TRANSFORMATION | ORGANIZATIONAL EXCELLENCE

As established in the U.S. DOT Strategic Plan FY 2022-2026, the Department's strategic goals are:

- Safety
- Economic Strength and Global Competitiveness
- Equity
- Climate and Sustainability
- Transformation
- Organizational Excellence



RD&T Strategic Plan FY 2022-2026 provides a national research vision to aid the Nation in continuing to push frontiers of transportation innovation through a set of Grand Challenges. The RD&T Strategic Plan:

- Establishes innovation principles to guide research.
- Identifies research priorities, objectives, strategies, and Grand Challenges in support of the Department's strategic goals.
- Looks outward to 2050 to explore how evolving technologies may shape the transportation systems and policies of the Nation.

SAFETY IS DOT'S HIGHEST PRIORITY

The foundation of our mission at the United States Department of Transportation is to ensure America has the safest transportation system in the world. In addition, the Department's work focuses on preventing and moderating economic disruptions, strengthening the transportation workforce, supporting robust and resilient freight systems and supply chains, reducing the impact of transportation on the environment, as well as mitigating and adapting to the impacts of climate change, and finding new solutions for planning, building, protecting, and operating transportation systems.

The DOT RD&T Strategic Plan provides a national research vision to aid the Nation in continuing to push frontiers of transportation innovation. It establishes transportation research priorities and strategies for the next five years and explores how evolving technologies may shape the transportation systems and policies of the Nation. While we cannot predict the dramatic and dynamic transportation system changes that might occur, we can define the desired future and guide the research and innovation to attain that future through research, coordination, engineering, and investments.

PNT is a critical element in meeting DOT's strategic goals and priorities and is a foundational element for enacting the RD&T Grand Challenges.

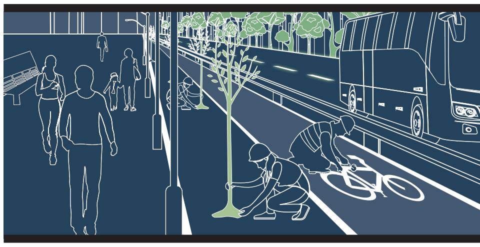
The following section describes the alignment of the PNT Strategic Plan goals with goals described in DOT's Strategic Plan and the RD&T Strategic Plan.

Safety & PNT

A DOT goal is to make our transportation system safer for all people and advance a future where transportation-related serious injuries and fatalities are eliminated. Strategic objectives as defined under the Safety goal in the DOT Strategic Plan include:

- Ensuring a Safe Public Transportation System that protects urban and rural communities and travelers, including vulnerable populations, from health and safety risks.
- Building based on Safe Designs of transportation infrastructure and systems to improve safety outcomes.
- Strengthening of Critical Infrastructure Cybersecurity by building in resilience to protect against disruption from cyber and other attacks.
- Ensuring the health, safety, and well-being of transportation workers and first responders.
- Strengthening Safety Systems by using informed data-driven decision-making and applying comprehensive approaches such as the Safe System approach and safety management systems for all modes.

With respect to the RD&T Strategic Plan, DOT intends to focus research on a Grand Challenge of achieving zero fatalities through studies on human factors, data-driven system safety, and cybersecurity.



- Human Factors
- Data-Driven System Safety
- Cybersecurity

Grand Challenge: Zero Fatalities

Advance a future without transportation-related serious injuries and fatalities.

PNT is essential for meeting these goals and ensuring safety across all modes of transportation and ensuring resiliency during GPS outages. Key areas where PNT is critical include the following examples:

- **Safe Rail Systems:** PNT technologies are embedded within rail systems and are used for rail systems safety, security, precision, and efficiency in controlling train movements. PNT also supports signal systems that authorize train movements to allow shared track usage between freight and passenger rail.
- **Highly Automated Transportation Systems:** PNT plays a critical role in the ever-evolving cooperative and automated technologies and systems as they are more broadly implemented and integrated into today's transportation environments. A prime example is connected and automated vehicles that need to integrate safely and effectively onto our roadways and into our air space with human drivers and pilots. Reliable and accurate communications with position and timing data are essential—timing even more so for safety and security of critical infrastructure. As cyber threats turn into attacks, the ability to close system interfaces in real-time prevents greater widespread degradation.
- **NextGen Aviation:** The comprehensive suite of state-of-the-art PNT technologies and procedures enable aircraft (and spacecraft) to move safely and more directly from Point A to Point B. PNT data allows operators to achieve the benefits of performance-based navigation (PBN) of the National Airspace System (NAS) by implementing procedures such as segregating traffic between airports, arrival and departure paths, and routes in proximity; increasing efficiency of sequencing, spacing, and merging when integrated with communication, surveillance and controller decision-support tools; allowing for reduced divergence between departure operations, resulting in increased departure throughput; providing safe access to airspace near obstacles and terrain; improving access to airports during poor weather conditions, especially for general aviation (GA) operations; and providing pilots with vertical guidance, resulting in more stabilized approaches and landings.[8]
- **Maritime Navigation:** PNT plays a major role in navigation (e.g., open seas, ports of entry, effective movement through canals and under bridges) and in the timing and synchronization for shipboard systems. GPS for maritime applications includes inputs to speed, heading, steering, radar and target information, ECDIS, UKC, and AIS information.

8 These procedures and other are described in FAA's Performance Based Navigation (PBN) Strategy at https://www.faa.gov/air_traffic/flight_info/aeronav/procedures/reports/media/PBN_NAS_NAV_Strategy.pdf

Economic Strength and Global Competitiveness & PNT

A DOT goal is to grow an inclusive and sustainable economy. DOT invests in the Nation's transportation system to provide American workers and businesses with reliable and efficient access to resources, markets, and good-paying jobs. The strategic objectives of this goal as defined in the DOT Strategic Plan include:

- Creating Good Jobs and Fiscal Health in support of American workers and businesses while building stronger and more sustainable regional and local economies.
- Restoring and Modernizing High-Performing Core Assets to improve the state of good repair, enhance resiliency, and expand beneficial new projects.
- Supporting Global Economic Leadership and the competitiveness of American businesses by increasing international collaboration on trade, standards, and research.
- Creating Resilient Supply Chains by modernizing infrastructure for safer and more efficient movement of goods while maintaining community and regional livability, as well as supply chain resiliency.
- Improving System Operations' Reliability and Connectivity to increase travel time reliability, manage travel demand, and improve connectivity.

With respect to the RD&T Plan, DOT intends to focus research on multimodal systems that can withstand and rapidly recover from severe disruptions.

- Resilient Supply Chains
- Advanced Asset Management
- System Performance
- Create Pathways to Good Quality Jobs

Grand Challenge: Resilient Supply Chains

Create a multimodal freight and passenger system that can withstand and rapidly recover from severe disruptions.

The role of PNT in meeting these strategic objectives is tied closely to availability of PNT services through today and tomorrow's PNT technologies and systems. A 2019 National Institute of Standards and Technology (NIST) sponsored-study[9] estimated that for the U.S. alone, GPS and PNT services have generated roughly $1.4 trillion in economic benefits (in 2017 dollars) in civilian and commercial uses since the 1980s. The study authors further estimate loss of these services would cost an average of $1 billion per day to the Nation, emphasizing the need for PNT resilience. This estimate is likely conservative, noting the study did not factor in loss of PNT to transportation—disruption or manipulation of PNT has the potential to adversely affect security and safety of transportation across the Nation.

9 See https://www.nist.gov/news-events/news/2019/10/economic-benefits-global-positioning-system-us-private-sector-study.

The ability to operate within GPS denied/corrupted environments is paramount for future transportation systems. The National Space-Based PNT Advisory Board has recommended to the National Space-Based PNT Executive Committee (EXCOM) to develop a compelling, quantitative way to accurately express economic damages attributable to extended disruptions to GPS[10], an activity recommended in this Plan's fifth strategic goal.

Equity & PNT

A DOT goal is to reduce inequities across our transportation systems and the communities they affect; and to support and engage people and communities to promote safe, affordable, accessible, and multimodal access to opportunities and services while reducing transportation-related disparities, adverse community impacts, and health effects. Strategic objectives include:

- Expanding Affordable Access to transportation jobs and business opportunities by removing barriers for individuals, businesses, and communities.
- Creating Wealth by reducing the effects of structural obstacles to building wealth.
- Empowering Communities through innovative public engagement with diverse stakeholders and thought leaders to foster exchange and ownership.
- Ensuring Proactive Intervention, Planning, and Capacity Building wherein equity considerations for disadvantaged and underserved communities are integrated into the planning, development, and implementation of all transportation investments.

With respect to the RD&T Strategic Plan, DOT intends to focus research on the grand challenge of achieving equitable mobility for all.

- Equity and Accessibility Assessment
- Mobility Innovation

Grand Challenge:
Equitable Mobility for All

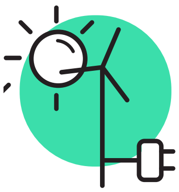
Create an equitable transportation system that provides safe, affordable, accessible, and convenient mobility options for all users.

The role of PNT in meeting these strategic objectives is in expanding access. Positioning and timing offer important information for travelers to be able to find and access available transportation either through near-term scheduling (e.g., route flexibility when a bus driver diverts to pick up a nearby disabled passenger just off the scheduled route) or in real-time (e.g., as services such as taxicabs or rideshare services provide). As technologically-advanced transportation systems reliant on PNT become commonplace, accessibility and independence for vulnerable road users (VRUs) (i.e., those at greater risk of injury in any collision with a vehicle) will increase.

10 See https://www.gps.gov/governance/advisory/recommendations/2023-01-PNTAB-27-chair-memo.pdf

VRUs are a particular focus for the Equity goal. Mobility innovation and accessibility requires enabling timing and communications, real-time data analysis, and service options (i.e., nearest option or cleanest fuel option) to feed advanced navigational tools that allow opportunities to be accessed by travelers in need or on demand. PNT is also a key enabler of dynamic use of curb space and ensuring not only safe uses, but fairness in accessibility to these public spaces.

Climate and Sustainability & PNT



A DOT goal is to tackle the climate crisis by ensuring transportation plays a central role in the solution. This includes substantially reducing greenhouse gas (GHG) emissions and transportation-related pollution as well as building more resilient and sustainable transportation systems to benefit and protect communities. Strategic objectives include:

- Establishing Paths to Economy-Wide Net-Zero Emissions by 2050 through reductions in air pollution and GHG emissions from transportation and advancing a sustainable transportation system.
- Improving Infrastructure Resilience by addressing the resilience of at-risk infrastructure.
- Designing in Flexibility and Adaptability for transportation system investments to accommodate and respond to changing needs and capabilities to provide long-term benefits.

With regard to the RD&T Strategic Plan, DOT intends to focus research on the Grand Challenge of achieving net-zero emissions through decarbonization and infrastructure solutions.

- Decarbonization
- Sustainable and Resilient Infrastructure

Grand Challenge: Net-Zero Emissions

Create a transportation system that supports an economy with net-zero GHG.

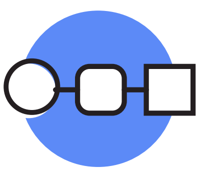
PNT will help meet these strategic goals by providing accurate positional data connected with other types of data, allowing analysis of many environmental problems that can be imported into geographic information system (GIS) software. PNT data can further support achieving substantial fuel efficiency and reducing GHG emissions for meeting climate and sustainability goals. Spatial aspects of the data can be analyzed with other information to create a far more complete understanding of a particular situation. This allows for accurate tracking of environmental disasters such as fires and oil spills, and will facilitate more efficient response times and clean-up efforts. Precise positional data can assist scientists in crustal and seismic monitoring. Monitoring and preservation of endangered species can be facilitated through PNT-based tracking and mapping.

Precision agriculture is a key example of a civil PNT use that can have significant impact on resource efficiencies and sustainability. According to a study by USDA's Natural Resource Conservation Service (NRCS), using precision agriculture on just 10 percent of farmland could cut fuel use by 16 million gallons, herbicide use by two million quarts, and insecticide use by four million pounds per year; and further save 180 billion cubic meters of water by 2030. A farmer cultivating a 6,500-acre farm would benefit by potentially saving 1,600 gallons of fuel per production cycle that could further avoid more than 400,000 kilograms of CO_2 emissions (equivalent to nearly 992,000 passenger car miles driven per year).[11]

The RD&T Strategic Plan notes that accessing the electrical grid to charge new low- and zero-emission vehicles requires PNT timing data, especially as we look to real-time road/induction-charging capabilities that transform our roadways into transportation-oriented microgrids.

Further, PNT supports environmental and infrastructure condition mapping to facilitate non-car commute patterns prioritized for safety, air quality, temperature, and light. In addition, PNT data is critical for assessing weather patterns that may have significant effects on critical infrastructure (e.g., the recent flooding and erosion from major storms that created roadway sinkholes, or tornadoes and hurricanes that make roads less accessible for response and recovery) both to harden and protect before an event and then to ensure humanitarian or critical resources can navigate and flow where needed most to help in recovery.

Transformation & PNT



A DOT goal is to design for the future, which requires investing in purpose-driven research and innovation to meet the challenges of the present and to modernize transportation systems of the future to serve everyone today and in decades to come. Strategic objectives include:

- Design for the future and renew commitment to science, learning, and innovation.
- Collaborate across the public and private sectors to foster an innovative ecosystem based on open data, honest dialogue, and shared insights. Transformation means investing in education and training to empower workers with the skills they need to succeed in today's economy and the economy of the future.
- Matching Research and Policy to advance breakthroughs. Foster breakthrough discoveries and new knowledge through high-risk, high-reward research driven by policy objectives.
- Experiment by identifying new ideas, new innovations, and new possibilities. Evaluate the opportunities and risks so the Department can support public benefits.
- Collaborate and Encourage Competition with diverse stakeholders to share noteworthy practices and accelerate the adoption of innovations and technologies.

11 See GPS World, April 2, 2021, J. David Grossmann at https://www.gpsworld.com/gps-the-environments-unsung-hero/

With respect to the RD&T Strategic Plan, DOT intends to focus research on the Grand Challenge of developing transportation system-of-systems, using data-driven insights and new or novel technologies to achieve seamless integration and interoperability.

- Integrated System-of-Systems
- Data-Driven Insight
- New and Novel Technologies

Grand Challenge: The Future of Transportation System-of-Systems

Develop connected intelligent infrastructure that provides safe, people-centered mobility.

The RD&T Strategic Plan notes the transportation sector is rapidly evolving to become one of the most innovative and dynamic areas of the Nation's economy. Developments in robotics, artificial intelligence (AI), sensors, mapping, data, cybersecurity, alternative fuels and electrification, and connectivity are driving innovations that offer opportunities to significantly advance DOT's mission. In the RD&T Strategic Plan, system-of-systems are based on machine-to-machine communications that have to sync with one another to transmit and receive information at precise times and at precise positions—this is as true for connected, cooperative transportation as it is for precision agriculture or international financial transactions—and thus implies a reliance upon PNT as a fundamental capability.

The role of PNT in meeting these strategic objectives is in transforming the transportation sector for the future, via evolution of PNT services, systems, technologies, and sources. For example, DOT's Complementary PNT Action Plan is focused on diversity of CPNT systems—to support consistent and reliable PNT services under adverse and threatening conditions (e.g., GPS denied jamming and spoofing scenarios). The ability for current and future transportation systems to operate within GPS denied/corrupted environments (including in tunnels or urban canyons) is paramount.

Organizational Excellence & PNT

A DOT goal is to strengthen our world-class organization and advance the Department's mission by establishing policies and processes, and creating an inclusive and innovative culture to effectively serve communities and responsibly steward the public's resources. Strategic objectives include:

- Deliver Responsive, Efficient, and Accessible Government Services.
- Attract, Recruit, Develop, Retain, and Train a Capable, Diverse, and Collaborative Workforce of highly skilled, innovative, and motivated employees by making DOT an employer of choice.
- Provide Data-Driven Programs and Policies by developing and managing data systems and tools to provide objective, reliable, timely, and accessible data to support decision-making, transparency, and accountability.
- Oversight, Performance, and Technical Assistance to increase competencies in DOT's mission-critical occupations and other areas, including program management. Improve program delivery and management of requirements, funding, contract performance, and program outcomes through effective planning, administration, and oversight of grants and contracts; increased technical assistance to stakeholders; and enhanced analytics and performance management services.
- Promote Sustainability Initiatives with a focus on a sustainable, clean, and resilient future for DOT's employees, buildings, and operations and meet the climate crisis challenge by establishing a path to achieve net-zero emissions from all operations by 2050. Eliminate GHG emissions from DOT buildings, in collaboration with other Federal partners.
- Strengthen Enterprise Cybersecurity and Address Risks by hardening DOT's enterprise information and communications technology against cyber threats.

With regard to the RD&T Strategic Plan, DOT intends to focus on technology transfer and deployment activities.

- Technology Transfer
- DOT Federal Laboratories
- University Transportation Centers (UTCs)
- Small Business Innovation Research (SBIR)
- Every Day Counts
- Bipartisan Infrastructure Law (BIL) Innovation Program

Goal:

Create a world-class organization with the talent and capacity to guide and oversee the largest investment in the Nation's transportation infrastructure since the Eisenhower Administration.

The role of DOT in meeting these strategic objectives is in leading the civil coordination of and participating in the national and international planning and execution for the Nation's PNT policy (inclusive of EXCOM, the Executive Steering Group (ESG), National Space-Based PNT Systems Engineering Forum (NPEF), the Federal Radionavigation Plan (FRP), the Civil GPS Service Interface Committee (CGSIC), the GPS International Working Group (GIWG), the International Committee on GNSS (ICG), the International Space Exploration Coordination Group (ISECG) for lunar PNT, PNT standards development bodies, and others).

Focusing on assured PNT, two DOT UTCs have been established under BIL funding grants. These UTCs are focused on assured and resilient PNT under the cybersecurity topic area:

- Center for Assured and Resilient Navigation in Advanced Transportation Systems (CARNATIONS)—led by the Illinois Institute of Technology
- Center for Automated Vehicle Research with Multimodal AssurEd Navigation (CARMEN)—led by The Ohio State University

As the Civil Lead, DOT can advance PNT by enabling research, coordination, and operations that will directly impact the safety, equity, reliability, and modernization of the Nation's transportation system as well as other consumer services, such as agriculture, banking, finance, telecommunications, and resource exploration. PNT has become an essential part of all of these uses (and others) and increasingly impacts all sectors of the U.S. economy.

WHEN PNT IS DISRUPTED, MANIPULATED, OR USED IMPROPERLY

Loss, degradation, or manipulation of PNT services has significant safety, security, and economic impacts. Without accurate, reliable, and secure PNT services, our safety and security would be at risk and our lives would become challenging and unrecognizable.

The most recognizable and predominantly used PNT system today is GPS. GPS relies on a low power signal from space and is subject to cyberattacks, jamming, spoofing, denial of service, and other malicious actions. GPS is also susceptible to natural interference events, e.g., space weather. Degraded, denied, and/or manipulated PNT or PNT that is used improperly can lead to disastrous and sometimes fatal consequences.

Our civil use of PNT is at a transition point whereby technologies and systems that had once used PNT data for basic navigational situational awareness now increasingly rely on PNT for precise and accurate positioning and timing. As these technologies are becoming more sophisticated, so are the types of malicious behaviors used to create disruption—spoofing, jamming, and denial of service.

Disruptions or Manipulation such as Jamming and Spoofing Result in Dangerous Navigation

In recent years, PNT services delivered through worldwide GNSS systems have increasingly been subject to spoofing and jamming attacks that alter both positioning and timing, as depicted in Figure 1. These types of malicious behaviors are becoming more prevalent and can have serious consequences associated with delayed or spoiled goods, frozen computers and missing money, more serious crimes, physical danger and injuries, and even fatalities.

There have been multiple reported instances of spoofing attacks in the eastern and central Mediterranean Sea, Persian Gulf, and the Red Sea. In one spoofing attack, a North Atlantic Treaty Organization (NATO) ship's crew in Odessa, Ukraine, saw their position being presented as Crimea.

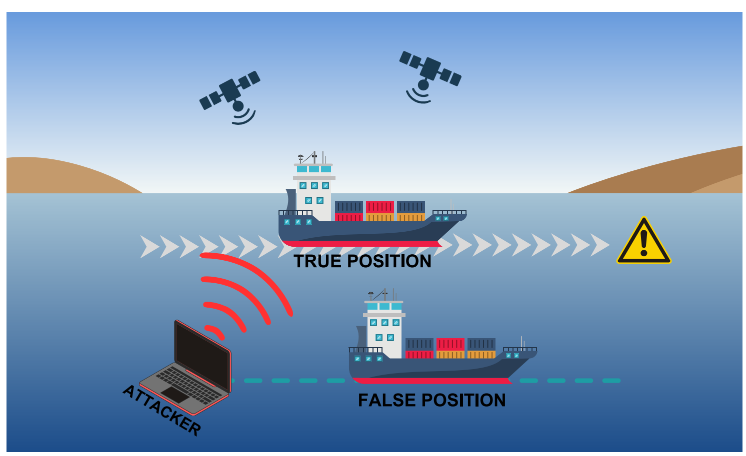


Figure 1: Image of a Ship's Position Being Spoofed (Credit DOT)

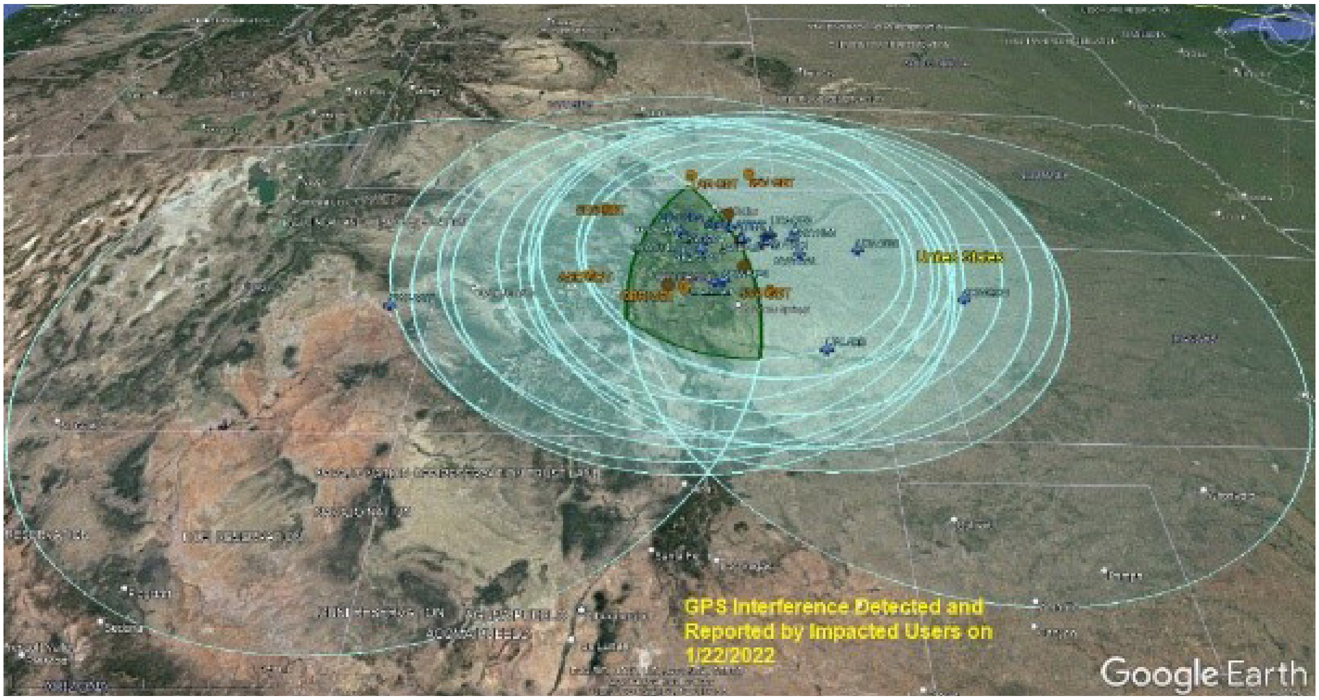


Figure 2: GPS Interference Detected and Reported by Aviation Impacted Users on 01/22/2022 (Credit FAA)

These issues are particularly troubling when they affect aviation, as illustrated in Figure 2, which provides an example of the breadth of detected GPS interference around the terminal and air route airspace.[12] The U.S. has faced numerous similar incidents in the past several years, notably:

- As illustrated in Figure 2 above, a January 2022 event at and around the Denver, Colorado airport took 33 hours to resolve, during which time pilots and air traffic controllers had to rely upon legacy navigation aids and aircraft vectoring to meet operational demands and safety requirements within a 236 nautical mile area (271.6 statute miles). At the same time, multiple ground infrastructure facilities from rail, emergency response, medical, and digital land mobile radio communications reported losing GPS signal reception and timing synchronization as well.
- An October 2022 event at and around the Dallas-Fort Worth and Houston Terminal Radar Approach Controls (TRACON) experienced a similar outage that took 44 hours to restore normal operations. To date, the source of the disruption is still under investigation.

These events are expanding internationally. Over 20 separate incidents of fake GPS signals were reported in September 2023 in the geographic area of Turkey and Iraq—had the pilots not understood that the signals were spoofed, they might have navigated into Iranian airspace without proper clearances. Based on investigations, it appears the issue went beyond false coordinates—the incidents appeared to have also resulted in failures of navigation systems including inertial referencing systems becoming unusable, sensor inputs failing, and internal system clocks failing. Again, legacy navigation aids and air traffic controller navigation guidance had to be utilized.

12 Image courtesy of DOT. Area of Interest calculated and derived from direct user filings into DOT official reporting systems. For additional information on this incident, please see https://www.cisa.gov/sites/default/files/2023-02/CISA-Insights_GPS-Interference_508.pdf.

Figure 3: Incorrect GPS instructions can lead to vehicles driving off of the road and into lakes, rivers, and other bodies of water. (Source: Adobe Stock)

Human Factors Challenges

Overreliance and "blind faith" in GPS have led vehicle operators to create hazards for travelers or sent drivers into rivers and lakes.

Reliance upon navigation aids has grown and, while maps have improved, these types of incidents still occur as drivers pay less attention.[13] In 2011, a passenger vehicle with three occupants relied upon GPS to reroute; they took what they thought was a road that would lead them to the highway. Instead, their vehicle entered a lake and sank in deep water. The "road" turned out to be a boat launching ramp. All three managed to get out safely, but by the time the tow truck arrived, the vehicle was completely submerged. In 2013, a similar incident turned deadly when a driver drove off the edge of a bridge that had washed away.

This issue does not only pertain to drivers. In 1995, the Panamanian passenger ship *Royal Majesty* grounded on shoals about 10 miles east of Nantucket Island, Massachusetts, while enroute from Bermuda to Boston. The cruise ship was state-of-the-art and had every navigation aid available at that

13 See https://theweek.com/articles/464674/8-drivers-who-blindly-followed-gps-into-disaster and https://people.com/human-interest/father-of-2-dies-after-gps-sent-him-to-a-bridge-that-was-destroyed-in-2013-avoidable-tragedy/

time. However, when the GPS antenna became disconnected, and despite an alarm condition shown on the display, the crew still trusted the technology and relied upon the system as the company's operating instructions required. The National Transportation Safety Board determined the probable cause was the watch officers' overreliance on the automated features of the integrated bridge system, the cruise line's failure to provide adequate training, and deficiencies in the design and implementation of the integrated bridge system. It was further complicated by the second officer's failure to take corrective action despite several cues the vessel was off course.[14] Figure 4 shows the location of the grounding and an image of the grounded ship.

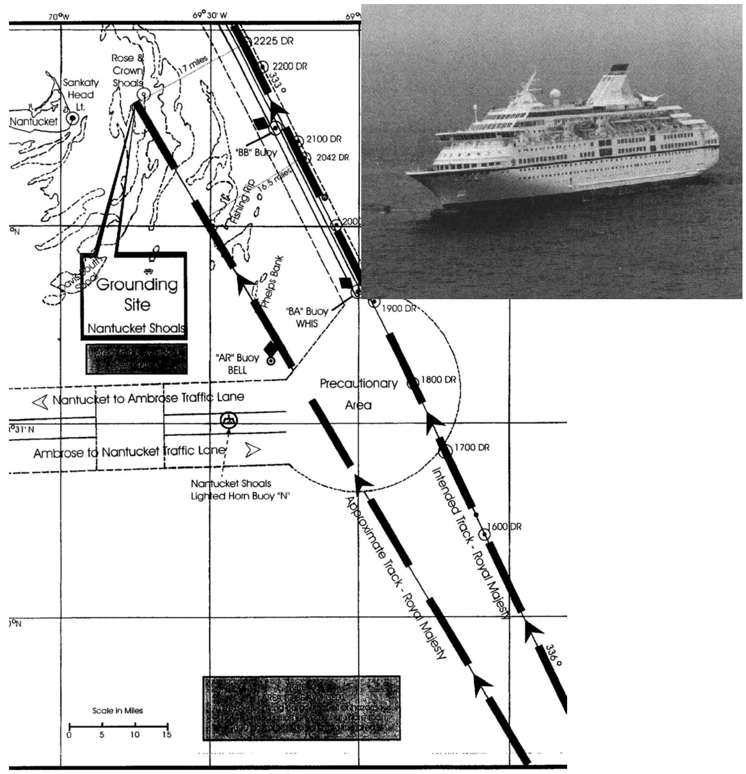


Figure 4: Image of grounded Panamanian passenger ship and map of the location of the shoals (Credit DOT)

Despite roadway signs and guidance from the Federal Motor Carrier Safety Administration (FMCSA), it is unfortunately still too common to see trucks and other tall vehicles hit low bridges and overpasses. As shown in Figure 5, bridge strikes and ensuing damages occur approximately 15,000 times a year in the U.S.[15] Similar events have occurred with buses, endangering multiple lives. PNT and additional sources of PNT systems that have access to accurate bridge height data have the ability to alert drivers and help overcome this human factors challenge.

Figure 5: Damage caused by a truck driver overestimating the height of the overpass (courtesy of U.S. DOT)

14 See National Transportation Safety Board Marine Accident Report: Grounding of the Panamanian Passenger Ship Royal Majesty on Rose and Crown Shoal Near Nantucket, Massachusetts, June 10, 1995, PB97-916401, NTSB/MAR-97/0, https://www.ntsb.gov/investigations/AccidentReports/Reports/mar9701.pdf.

15 See https://www.fhwa.dot.gov/bridge/preservation/docs/hif20087.pdf.

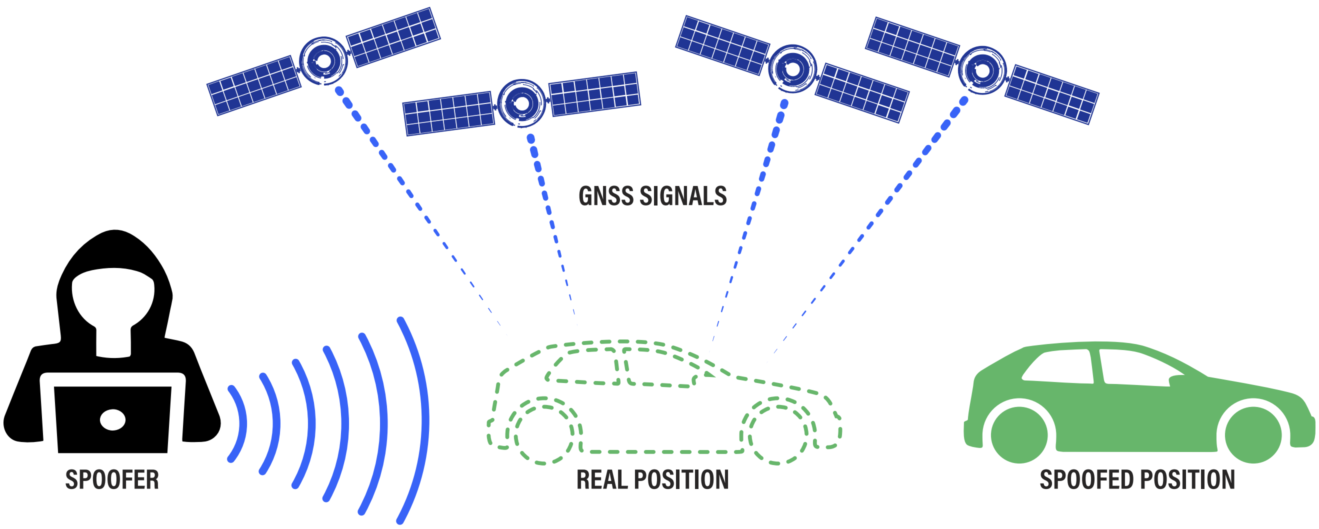


Figure 6: Image of Spoofing a Vehicle's Position on the Roadway (Credit DOT)

Automation and Increasingly Rigorous Cybersecurity Requirements

As automated systems become increasingly common, PNT requirements are becoming more rigorous, necessitating new ways to mitigate the increasing amount of cybersecurity issues. With advances in PNT technologies and systems, DOT intends to focus on partnering with industry to enhance resilience through increased cybersecurity messages.

There is a global trend of increasing GNSS interference, both accidental and deliberate, in radio bands crucial for highly automated transportation systems (HATS). Civil GNSS jamming and spoofing, as depicted in Figure 6, have evolved from a hypothetical threat to a verified vulnerability, which has now become a public safety hazard. The obvious risk for automated vehicles is loss of ability to produce an accurate, sustainable position, velocity, and time (PVT) solution in a global map with sufficiently high integrity. The risks for vehicle networks and transportation management systems are increasing traffic congestion and collisions due to inadequate or misleading situational information.

The vulnerability of externally sourced information vital to PNT and to situational awareness remains an open problem for HATS. Vehicle manufacturers, suppliers, fleet operators, and human drivers/pilots have some knowledge of threats to PNT, but do not fully appreciate the threats' scope and seriousness. They tend to rely on security and resiliency schemes that address only minimum requirements, leaving serious weaknesses exposed.

PNT PRINCIPLES: PROTECT, TOUGHEN, AUGMENT, AND ADOPT (PTAA)

If we do not act to mitigate present and emerging threats to PNT, our world could become less efficient, and most critically, significantly less safe and secure. People will not be able to use cell phones, bank electronically, or navigate reliably from point A to point B. Making PNT systems more resilient (i.e., less susceptible to spoofing and jamming) is paramount for national and economic security.

A key objective of this PNT Plan is to improve the overall PNT posture for the Nation using innovative tools, diverse PNT data sources, and advanced technological resiliency—also known as the Protect, Toughen, and Augment (PTA) principles developed by the National Space-Based PNT Advisory Board.[16]

Addressing these problems is essential to current Intelligent Transportation Systems (ITS) and emerging HATS that rely on PNT not just for navigation but for control. For instance, controls in automated vehicles, or controls for future fully connected and interoperable systems, where all nearby devices in vehicles, with pedestrians, or with vulnerable road users can sense, fuse, and share information in real-time with each other and with smart roadway infrastructure such as traffic signals.

PTA is a critical set of principles, but they are not fully sufficient until they are put into use. Thus, Adoption extends these important principles to Protect, Toughen, Augment and Adopt (PTAA). PTAA initiatives focus on establishing greater resiliency, resulting in PNT services remaining consistent and available in the event of human-made or natural disruptions. Moreover, there is a focus on:

- Graceful degradation to ensure systems and services both alert users to disruptions, manipulations, and potential cessation with enough time to take action, but also maintain some degree of operational continuity instead of immediate failure and cessation.
- Resistance to harmful communications interference or disruptions.
- Rapid recovery.

16 See https://www.gps.gov/governance/advisory/recommendations/2018-09-topic-papers.pdf.

COMPLEMENTARY PNT

For the many civil uses—and in particular, the critical infrastructure and safety-of-life uses—PNT services must be available to support applications and use cases underground, underwater, and in space. Therefore, these uses require PNT services that are both independent and complementary to the space-based (GPS) services that support our air, surface, and maritime uses.

One critical PTAA initiative is known as "Complementary PNT," or CPNT, which incorporates other sources of positioning, navigation, and timing to complement or augment space-based PNT systems (e.g., GPS, GNSS) that rely on signals broadcast from satellites in Medium Earth Orbit (MEO). GNSS signals emanating from these space-based sources are received on Earth at very low power levels and, as a consequence, are vulnerable to intentional and unintentional disruptions. CPNT services are defined by their source location (space-based or terrestrial), their service volume (local at a fixed point versus regional or global versus interplanetary throughout the solar system), and their autonomy (dependent, requiring frequent refresh rates versus autonomous with no refresh needed once initialized.) Combined space-based PNT from GNSS and CPNT services have the ability to service a wider and more complex set of environments where PNT is needed, as illustrated in Figure 7.[17]

As the Nation expands beyond space-based PNT, the terrestrial, autonomous, and signals-of-opportunity solutions (and other new and emerging innovations) are pushing the technological envelope. With further refinements and work on standards, they offer an example of the opportunity in the near future to become mainstream complements of PNT systems. Table 3 identifies a subset of the list of technologies available today.

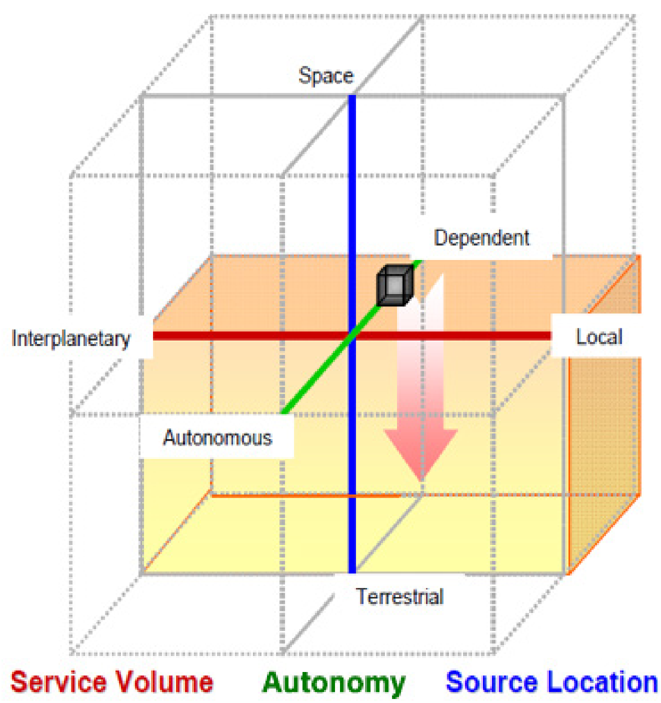


Figure 7: Architectural Trade Space for the PNT Architecture

17 : See the National PNT Architecture Study Final Report, page 35 at https://rntfnd.org/wp-content/uploads/National-PNT-Architecture-Study-Final-Report.pdf.

Table 3: Existing and Operational Sources of PNT

Space-Based PNT

- Global Navigation Satellite Systems
- Augmentations to GNSS
- Two-way satellite time transfer (TWSTT)
- Low Earth Orbit (LEO) Satellites

Dedicated Terrestrial

- Instrument landing systems (ILS)
- Very high frequency (VHF) omnidirectional range (VOR)
- Distance measuring equipment (DME)
- Tactical air navigation (TACAN)
- Nondirectional beacons (NDB)
- Radio station WWVB (LF), WWV, and WWVH signals for time realization and distribution
- Direct telecommunications/fiber optic links

Signals of Opportunity

- High Definition TV
- Telecommunications
- Clouds/Edge Data/HD Mapping
- Low Earth Orbit (LEO) Satellites

Autonomous

- Inertial systems
- Light Detection and Ranging (LiDAR)
- Vision systems
- Clocks

Internet Time Service (ITS)

CPNT efforts address Federal policy governing PNT programs and activities for national and homeland security, civil, commercial, and scientific purposes, including the intent of Executive Order 13905 on Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services (EO 13905) and Space Policy Directive 7, The United States Space-Based Positioning, Navigation, and Timing Policy (SPD-7), to increase PNT resiliency and increase "responsible use" with PNT users.[18]

To advance CPNT efforts, in 2020, DOT conducted field demonstrations of candidate CPNT technologies that could offer complementary service in the event of PNT and GPS disruptions. The purpose was to gather information and evaluate new PNT technologies for their technology readiness level (TRL) and their ability to work in the absence of GPS.

CPNT systems that were tested and demonstrated include technologies and solutions such as fiber-optic timing systems, localized map matching databases, inertial measurement units (IMU), ultra-wideband (UWB) technologies; or terrestrial radio frequency (RF) PNT technologies across low frequency (LF), medium frequency (MF), ultra-high frequency (UHF), and Wi-Fi/802.11 spectrum bands.

18 See SPD-7 at https://www.gps.gov/policy/docs/2021/ and EO13905 at https://www.federalregister.gov/documents/2020/02/18/2020-03337/strengthening-national-resilience-through-responsible-use-of-positioning-navigation-and-timing.

Eleven candidate technologies demonstrated positioning or timing functions during the evaluations.

The demonstration program resulted in a 2021 Report to Congress, *Complementary PNT and GPS Backup Technologies Demonstration Report* (2021 Demonstration Report).[19] While this demonstration was a snapshot in time, there were two critical recommendations from the demonstration:

1. U.S. DOT should develop system requirements for PNT functions that support safety-critical services.
2. U.S. DOT should adopt, adapt, or develop standards, test procedures, and monitoring capabilities to ensure that PNT services, and the equipage that utilize them, meet the necessary levels of safety and resilience identified in Recommendation 1.

As part of its ongoing responsibilities as civil PNT lead, the Department has developed and is enacting a Complementary PNT Action Plan[20] to drive CPNT adoption across the Nation's transportation system and within other critical infrastructure sectors. The plan describes actions DOT will pursue over the next several years, including:

- Engaging PNT stakeholders
- Monitoring and supporting the development of CPNT specifications and standards
- Establishing resources and procedures for CPNT testing and evaluation
- Creating a Federal PNT Services Clearinghouse
- Acquiring domain-specific CPNT services for Federal owners and operators of critical infrastructure

Taken together with efforts of other Federal partners, these initiatives are expected to continue to strengthen the resilience of the Nation's PNT-dependent systems, resulting in safer, more secure critical infrastructure.

19 See https://www.transportation.gov/sites/dot.gov/files/2021-01/FY%2718%20NDAA%20Section%201606%20DOT%20Report%20to%20Congress_Combinedv2_January%202021.pdf.

20 Located at https://www.transportation.gov/sites/dot.gov/files/2023-09/DOT%20Complementary%20PNT%20Action%20Plan_Final.pdf

PNT STRATEGIC GOALS

- Advance PNT Services and Capabilities
- Build Resiliency into Federal use of PNT Services and Capabilities
- Address PNT Cybersecurity
- Ensure Spectrum Availability and Protection for PNT Services
- Lead Civil PNT Coordination

This section presents the five inter-related PNT Strategic Goals:

- Advancing PNT capabilities and services
- Integrating resiliency into Federal use of PNT
- Incorporating cybersecurity risk mitigations into PNT system design
- Protecting PNT spectrum from harmful interference and ensuring availability of spectrum
- Coordinating and leading PNT efforts with domestic and international partners, inclusive of policymakers, experts, researchers, industry stakeholders, standards bodies, workforce developers, and educators; to address priorities, exchange information on the latest work and advancements, and eliminate redundancies.

After presenting each goal's vision, objective, and desired outcome, this section provides a short background on some of the fundamental building blocks that shape and guide each PNT strategic goal. A summary of critical activities concludes each PNT strategic goal description.

Vision

The Goal's Objective

Desired Outcomes

GOAL 1

Advance PNT Capabilities & Services

Vision

Advance PNT capabilities and services for critical infrastructure sectors and civil applications and innovations, including future services such as highly automated safety systems; and assuring PNT capabilities to support safe integration of new technologies, such as automated vehicles and AAM, into our transportation environments. Working with the private sector and academia, ensure a diversity of options for delivering reliable, resilient, cybersecure, and accurate PNT data.

Strategic Goal Objective

To advance and evolve leading-edge PNT capabilities and services through research and development to meet current and future safety-critical requirements and ensure that trusted PNT data is available to a wide range of civil users.

Desired Outcomes

PNT users across the Nation advance toward an "ideal" PNT Architecture that continuously meets service requirements for the Nation's civil PNT needs and positions U.S. industries as global leaders in providing state-of-the-art PNT systems and technologies that can provide complementary PNT services.

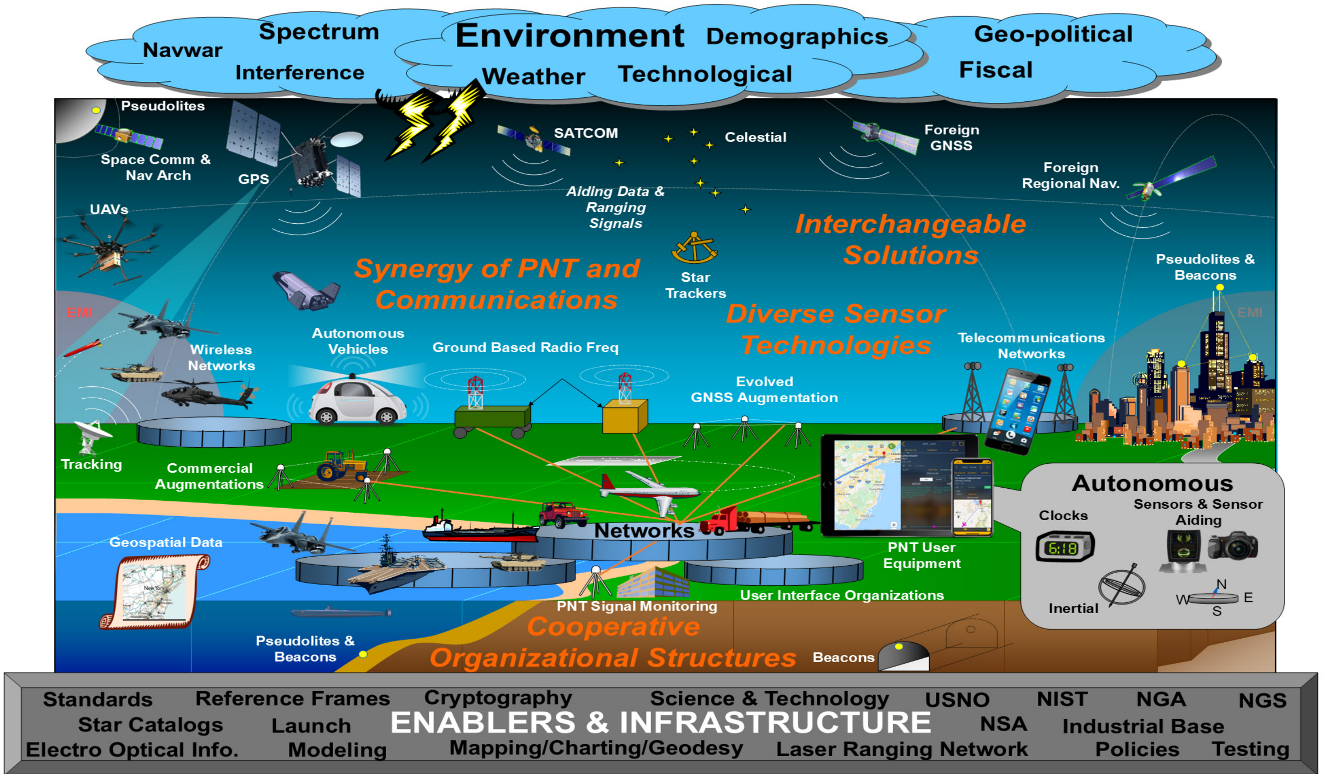


Figure 8: National PNT Architecture (Credit DOT)

NATIONAL PNT ARCHITECTURE

The National PNT Architecture aids in envisioning the advancements needed for the performance and capabilities of the technologies and systems that comprise the PNT ecosystem. It also incorporates the considerations influencing the operating environment as well as the enablers and infrastructure necessary for applications that rely upon PNT services. The National PNT Architecture shown in Figure 8 illustrates current and future PNT capabilities and applications and focuses on an evolutionary transformation to overcome PNT capability gaps.

The National PNT Architecture provides recommendations and offers guidance that will help civil agencies and industry implement activities that will overcome PNT capability gaps, predominantly resulting from the limitations of GPS; and it provides an actionable path for CPNT systems and services. It is the basis of an interagency implementation action plan consisting of transition elements that address the PNT Architecture strategy and vectors.[21]

21 Located at https://www.transportation.gov/sites/dot.gov/files/2023-09/DOT%20Complementary%20PNT%20Action%20Plan_Final.pdf

The National PNT Architecture identifies the key component interfaces and institutional organizations for which coordination is essential. The Architecture further notes other external and environmental factors that might create unintended effects to PNT. Lastly, it also structures a path for achieving the goals and guiding principles that are the foundation of a Vision, Architectural Strategy, and four supporting Vectors under which nineteen recommended initiatives are described to implement the National PNT Architecture, as illustrated in Figure 9.[22]

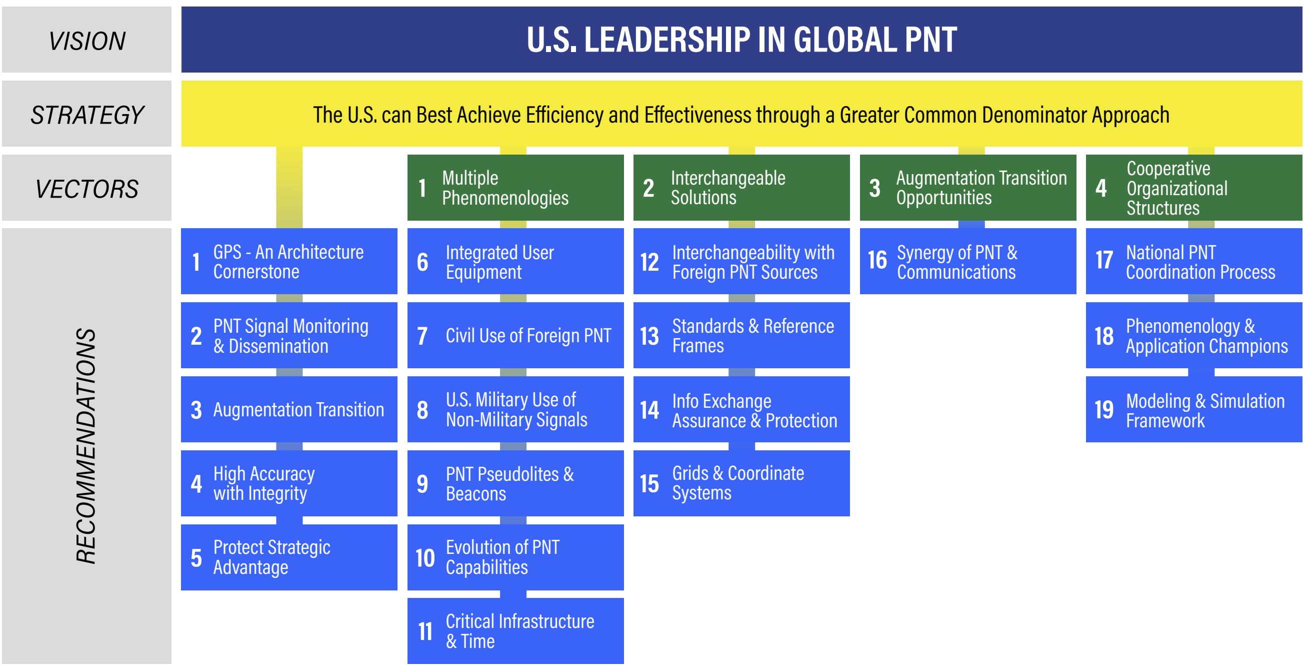


Figure 9: Path to Achieving the National PNT Architecture (Credit DOT)

22 See https://www.transportation.gov/pnt/national-positioning-navigation-and-timing-pnt-architecture

Critical Initiatives to Advance PNT Capabilities and Services in Partnership with Federal Agencies, Industry, and Academia

As the lead USG department for civil PNT, DOT has planned for and is enacting a proactive set of initiatives critical to achieving this strategic goal. These initiatives are described in three primary areas:

1. PERFORM PNT REQUIREMENTS ANALYSES ON NEW AND CRITICAL EMERGING TECHNOLOGIES

- Analyze PNT needs for new use cases such as highly automated transportation systems, requirements for time/frequency sources, and PNT use in space transportation.
- Work with the DOT operating administrations and USG Departments and Agencies to examine advances, innovations, and new concepts associated with PNT, and seek to match research and policy to advance breakthroughs.
- Support the development of experiments to demonstrate optical time transfer between the surface and space, both to reduce reliance on radio frequency spectrum and to utilize the full precision of optical atomic clocks for worldwide time transfer and geodesy.

2. MANAGE AND MODERNIZE SPACE-BASED PNT

- As per Space Policy Directive 7, perform responsibilities such as:
  - Develop space-based PNT requirements for civil applications including interoperability and other characteristics (i.e., maximum allowable power levels, etc.) when combining space-based PNT with new technologies and systems. This includes coordinating with National Aeronautics and Space Administration (NASA), DOD, and Department of Commerce (DOC) to develop requirements for GPS support of space operations and science in higher orbits.
  - Manage and modernize space-based PNT for civil applications. This includes addressing challenges of integration of emerging constellations of LEO satellites into the broader GNSS system.
  - Address performance monitoring and interference detection capabilities for civil space-based PNT services, including developing and supporting deployment of tools to perform civil signal performance monitoring such as:
    - Completing implementation of a full Civil Signal Monitoring System (CSMS) for Civil GPS Signals (L1C, L2C, L5, and L1 C/A).
    - Developing tools to monitor and assess GNSS L-band broadcasts.
    - Addressing the GPS Integrity Support Message (ISM) for Advanced Receiver Autonomous Integrity Monitoring (ARAIM).
    - Continuing ongoing PNT operations, maintenance, and calibration.

  - Enhance PNT Resiliency.
  - Develop methods for space-based PNT data and signal authentication.
- Engage stakeholders nationally and internationally. This includes representing the civil agencies to champion their needs in the development, acquisition, management, and operations of GPS and its augmentations.

3. SUPPORT DEVELOPMENT AND ADOPTION OF COMPLEMENTARY PNT CAPABILITIES

- Facilitate adoption of CPNT recommendations and technologies to address civil needs, including transportation. Support rulemaking where applicable to adoption.
- Establish field test ranges to evaluate CPNT technologies and conduct vulnerability assessment and testing.
- Create field, flight, and space test capabilities and protocols for maturation and new components to allow vendors to understand basic requirements that qualify for effective and secure operations.
- Support the development and distribution of maps of sufficient resolution for navigation using quantum and classical sensors based on gravity and magnetic field anomalies.
- Assess interoperability and other characteristics (i.e., maximum allowable power levels, etc.) of new technologies and systems.
- Establish PNT standards and requirements and conduct vulnerability testing and analysis.
- Engage with PNT technology vendors and critical infrastructure sectors and support technology transfer.
- Work with partners from DOD and the State Department to address International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR) considerations for use of multi-element Controlled Reception Pattern Antennas (CRPA) in civil applications.
- Support research and development of quantum PNT sensors (e.g., optical atomic clocks, inertial navigation sensors using atom interferometers, etc.) and enabling component technologies (e.g., photonic integrated circuits, low-noise electronics, etc.).

Goal 2

Build Resiliency into Federal PNT Services and Capabilities

Vision

Partner with civil Federal Departments and Agencies in enacting a coordinated civil approach for protecting against, responding to, and recovering from disruptions or manipulation of PNT services with a primary focus on safety and security.

Strategic Goal Objective

To incorporate resiliency throughout the current and future Federal PNT ecosystem—within organizations and into systems and technologies utilized by Federally owned and operated user applications—to ensure continuity of services and operations, employing the principles of detect, prevent, respond, and recovery through diversity of equipment, assessment of risk tolerance, and prioritization of application criticality.

Desired Outcomes

The Federal government moves toward "responsible use of PNT services" and incorporates the deliberate, risk-informed use of PNT into Federal decisions, procurements, and technology and system operations. Complementary sources of PNT data are available that meet the timing and positioning requirements necessary to support civil uses and are adopted into end user applications. Federal, commercial, and civil organizations establish response and recovery plans to address PNT service disruptions.

Implementing resiliency requires a multi-pronged strategic approach at the technology and systems levels, as well as at the user and organizational levels. To facilitate resiliency within critical infrastructure applications of PNT, a Presidential Executive Order focuses on responsible use of PNT in acquisitions and decision-making, including seeking proven, reliable, and trusted complementary sources of PNT that incorporate appropriate cybersecurity controls, as described below.

"It is the policy of the United States to ensure that disruption or manipulation of PNT services does not undermine the reliable and efficient functioning of its critical infrastructure. The Federal Government must increase the Nation's awareness of the extent to which critical infrastructure depends on, or is enhanced by, PNT services, and it must ensure critical infrastructure can withstand disruption or manipulation of PNT services."

Executive Order (EO) 13905, Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing (PNT) Services[23]

Executive Order 13905

A key, fundamental building block for PNT resiliency is EO 13905, which directs Federal Agencies to protect the Nation from disruption or manipulation of systems that form or use PNT data and information vital to critical infrastructure and technology-based industries. EO 13905 emphasizes two important activities designed to increase PNT resiliency:

(1) "Responsible use of PNT services," meaning the deliberate, risk-informed use of PNT services by owners and operators of critical infrastructure, including their acquisition, integration, and deployment, such that disruption or manipulation of PNT services minimally affects national security, the economy, public health, and the critical functions of the Federal Government.

(2) Development of "PNT profiles" for critical infrastructure (systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on national security, national economic security, national public health, and safety, or on any combination of those matters) aligned to standards, guidelines, and sector-specific requirements for security and resiliency; the profiles are selected for a particular system to address the potential disruption or manipulation of PNT services.

23 EO 13905 can be found at https://www.federalregister.gov/documents/2020/02/18/2020-03337/strengtheningnational-resilience-through-responsible-use-of-positioning-navigation-and-timing.

Responsible Use of PNT Services

An important and underlying element of the PTAA principles is responsible use, which seeks to engage PNT users to assess risk and build resilience against disruptions when they specify, procure, and operate their PNT-enabled systems.

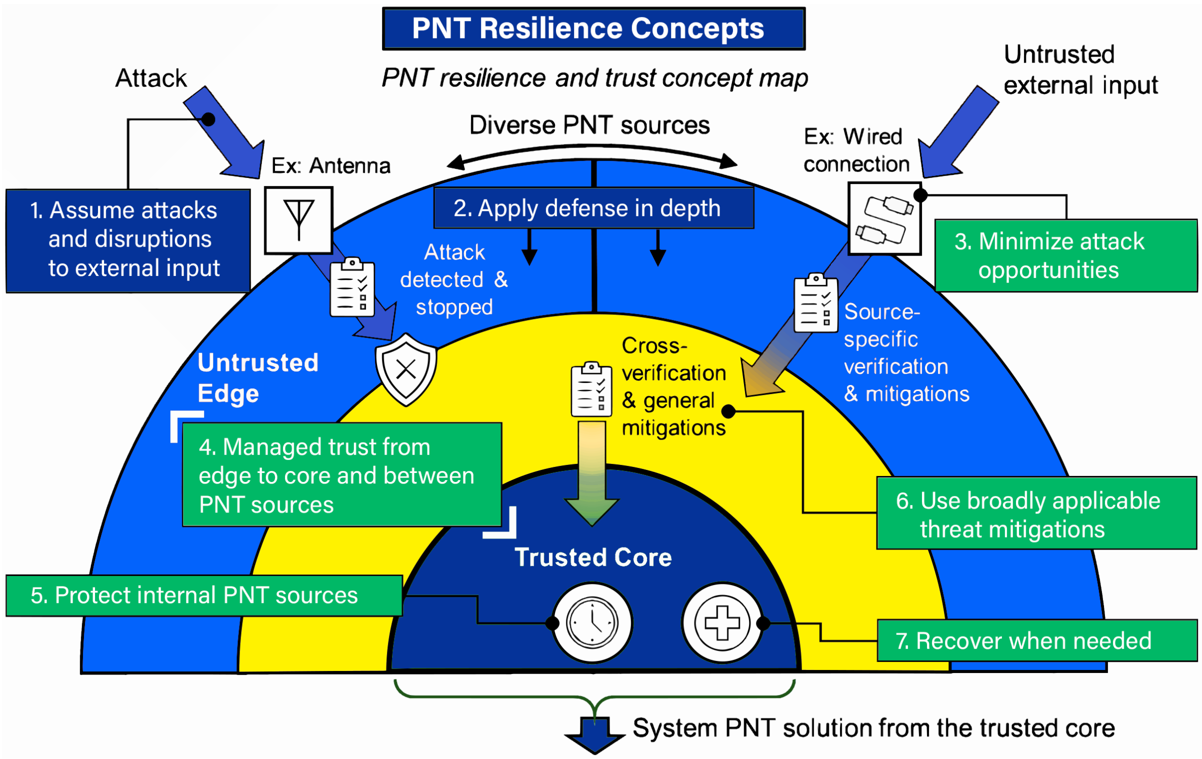


Figure 10: PNT Resilience Concepts (Credit DHS)[24]

Figure 10 from DHS illustrates a conceptual map for implementing PNT resilience and trust for users, while also identifying where and how risk is present within PNT technologies, systems, and applications. The graphic is drawn from the Resilient PNT Reference Architecture, which builds upon a conformance framework by combining cybersecurity principles (i.e., zero-trust architectures) with PNT resilience concepts and techniques.[25]

PNT Profiles

EO 13905 also directed the DOC to develop a foundational PNT profile, based on the DOC's NIST Cybersecurity Framework (CSF). NIST developed the Foundational PNT Profile, NISTIR 8323.[26]

24 See https://www.dhs.gov/science-and-technology/publication/resilient-pnt-reference-architecture, pg. 14.

25 See https://www.dhs.gov/science-and-technology/publication/resilient-pnt-reference-architecture.

26 See https://www.nist.gov/cyberframework for the latest version; also see https://csrc.nist.gov/pubs/ir/8323/r1/final.

The PNT Profile is a tool for mapping systems and technologies, assets, resources, and operational processes to guidance on practices and controls that could be used to achieve resiliency and cybersecurity outcomes.

The CSF process leads organizations through a definition of five core functions—Identify, Protect, Detect, Respond, and Recover—as shown in Figure 11. Using the CSF tool, the PNT Profile can be developed and tailored by any organization to focus on four components of PNT resilience and responsible use, as illustrated in Figure 12.[27] [28]

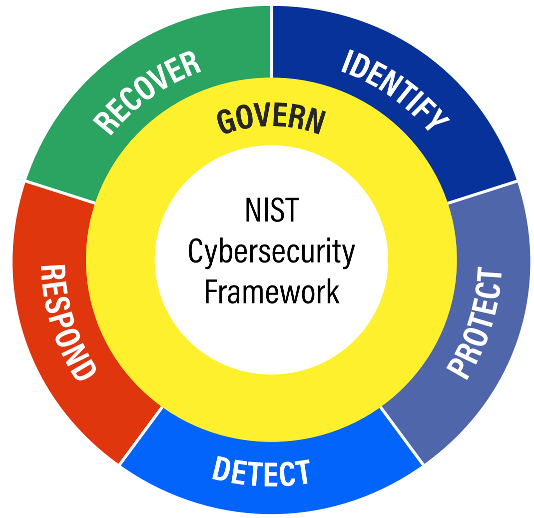


Figure 11: NIST CSF Core Functions (Credit NIST)

By implementing EO 13905, USG and civil PNT users gain greater resilience, as responsible use decisions, developments, and enactments of PNT profiles leads to technologies, systems, and critical infrastructure impervious to or 'robust' (i.e., zero downtime, hardened, etc.) against PNT cyber events (i.e., jamming and/or spoofing). This process is illustrated in Figure 12.

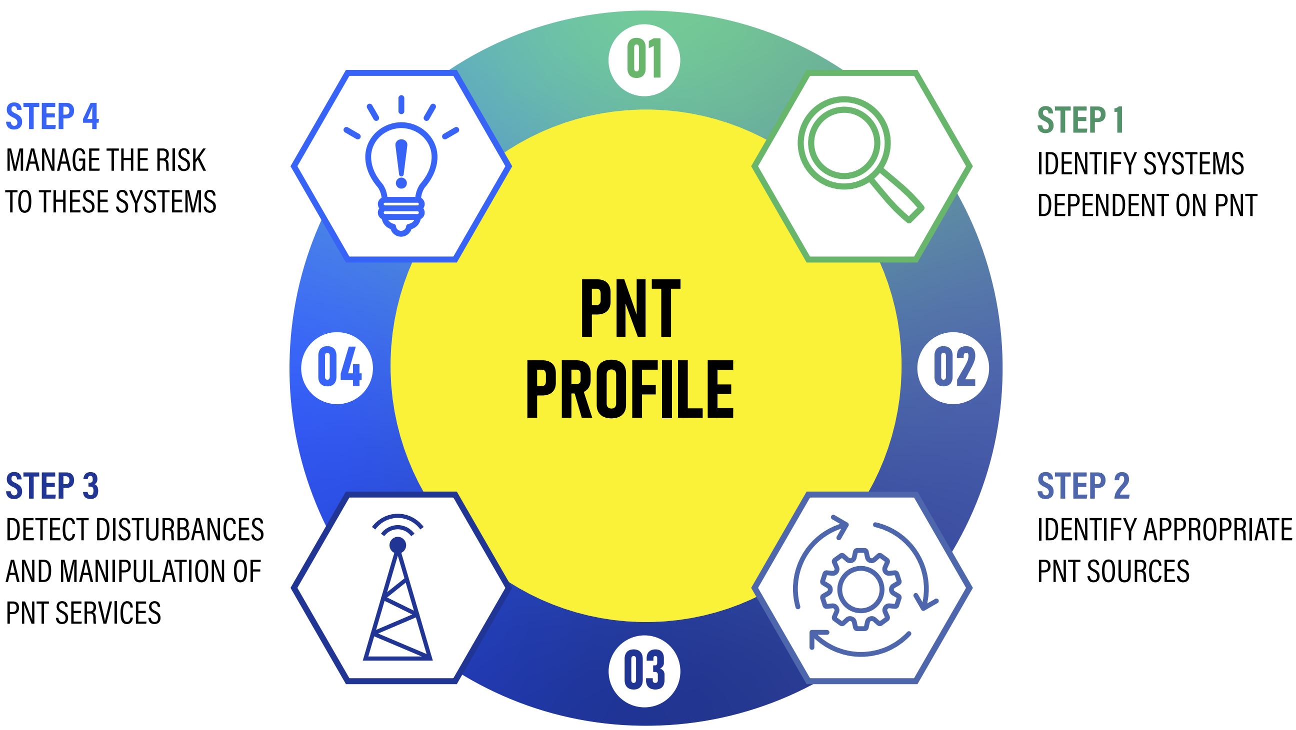


Figure 12: NIST PNT Cybersecurity Process to Address Resilience (Credit NIST and DOT)

27 For more details, see https://www.nist.gov/pnt.

28 For more detail, see: https://www.federalregister.gov/documents/2020/02/18/2020-03337/strengthening-national-resilience-through-responsibleuse-of-positioning-navigation-and-timing

Two major areas for PNT resilience pertaining to jamming and spoofing mitigation methods are:

- For Infrastructure (PNT Service Providers): A focus on building greater resilience into GPS, use of foreign GNSS from like-minded Nations, LEO Systems, and terrestrial CPNT systems.
- For Host Platforms (PNT Users): Incorporation of GPS/GNSS receiver multi-layer hardening technology including:
  - Antenna technology (e.g., controlled reception pattern antennas, and dual-antenna direction of arrival-based spoofing detection).
  - Space-time adaptive processing (STAP) and other signal processing (e.g., adaptive filters for single element antenna or STAP for multi-element CRPA), analysis of the cross ambiguity function (CAF) of a received GNSS signal to detect the presence of spoofing, adding the capability of processing and fusion of complementary PNT signals for improved performance and resilience.

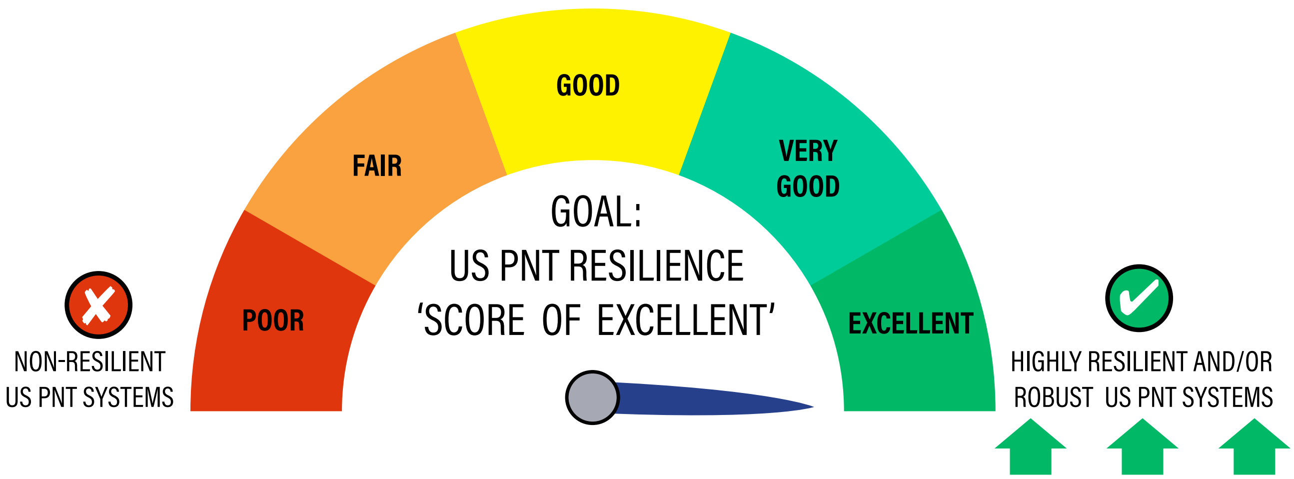


Figure 13: Illustration of the Desired Outcome of the PNT Resiliency Goal (Credit DOT)

Critical Initiatives to Build Resiliency into PNT Services and Capabilities

- Encourage PNT responsible use for safety-critical transportation applications by working with organizations to identify risks, assess the impact of those risks, and identify CPNT and other mitigation solutions, including:
  - DOT operating administration partners to develop and tailor the PNT profile for their industry sectors and conduct pilot projects to confirm the effectiveness of the tailored profile.
  - Critical infrastructure owners and operators to implement complementary sources for PNT services for greater resiliency and for civil, mission-critical use cases. Identify and promote, as appropriate, multiple, diverse CPNT systems or approaches for critical infrastructure and mission-essential functions (e.g., extended holdover time via optical atomic clocks).

  - Private sector and research organizations to create new receiver hardware (improved design of antennae) and software/firmware (ability to demodulate/decode even more sophisticated signals-in-space). The combination of hardware and software will also improve rejection of interference.
  - DOT civil partners (including research organizations and private sector) to evaluate concepts for CPNT infrastructure, systems, and other solutions for emerging and future PNT applications that are not addressed by existing PNT technology.
- Integrate the principles of Protect, Toughen, Augment, and Adopt throughout the National PNT Architecture.
- Perform vulnerability and assessment testing on innovative, emerging PNT resiliency solutions.
- In coordination with DHS, apply Federal contract language to drive use of conforming CPNT services so that users and manufacturers are encouraged to invest in resiliency.

Goal 3

Address PNT Cybersecurity

Vision

Cybersecurity for PNT evolves as a coordinated national and international response capability that is continuously monitoring for attacks (i.e., denial of service, jamming), false data, and other malicious behavior within the systems and across the PNT services, using data-driven methods and solutions.

Strategic Goal Objective

To build cybersecurity protections and mitigations (including encryption) into current and emerging PNT services, applications, and devices. Protect PNT data and systems from malicious behavior and unintended consequences and alert users of disrupted, degraded, or manipulated PNT.

Desired Outcomes

Critical PNT applications benefit from increased PNT cybersecurity; users trust that PNT data is safe, secure, accurate, and reliable.

PNT CYBERSECURITY

Traditionally, cybersecurity has offered a specific and focused approach to protection and security of computing systems, networks, user equipment, and other digital assets with measures that typically address cyberattacks. Strategies and tools include firewalls and gateways, intrusion detection, and antivirus and prevention software, among others. The National Security Memorandum on Critical Infrastructure Security and Resilience and the National Security Memorandum on Improving Cybersecurity for Critical Infrastructure Control Systems both note that "The cybersecurity threats posed to the systems that control and operate the critical infrastructure...are among the most significant and growing issues confronting our Nation. The degradation, destruction, or malfunction of systems that control this infrastructure could cause significant harm to the national and economic security of the United States." Cyber resilience takes a multidisciplinary approach in the engineering of trustworthy and secure systems and combines continuity, digital asset security, and organizational resilience using approaches such as:[29]

- Zero Trust Architectures.
- Security-by-Design and Security-by-Default.

DHS has documented these approaches within a key guiding document—**Resilient Positioning, Navigation, and Timing (PNT) Reference Architecture.**[30] According to DHS, a resilient PNT reference architecture advances PNT resilience concepts by incorporating applicable modern cybersecurity principles, and is designed around seven PNT resilience concepts (as illustrated in Figure 14), with the core principle being managed trust—derived from the Zero Trust Architectures concept, as a measure of limiting the impact of attacks when they penetrate systems.[31]

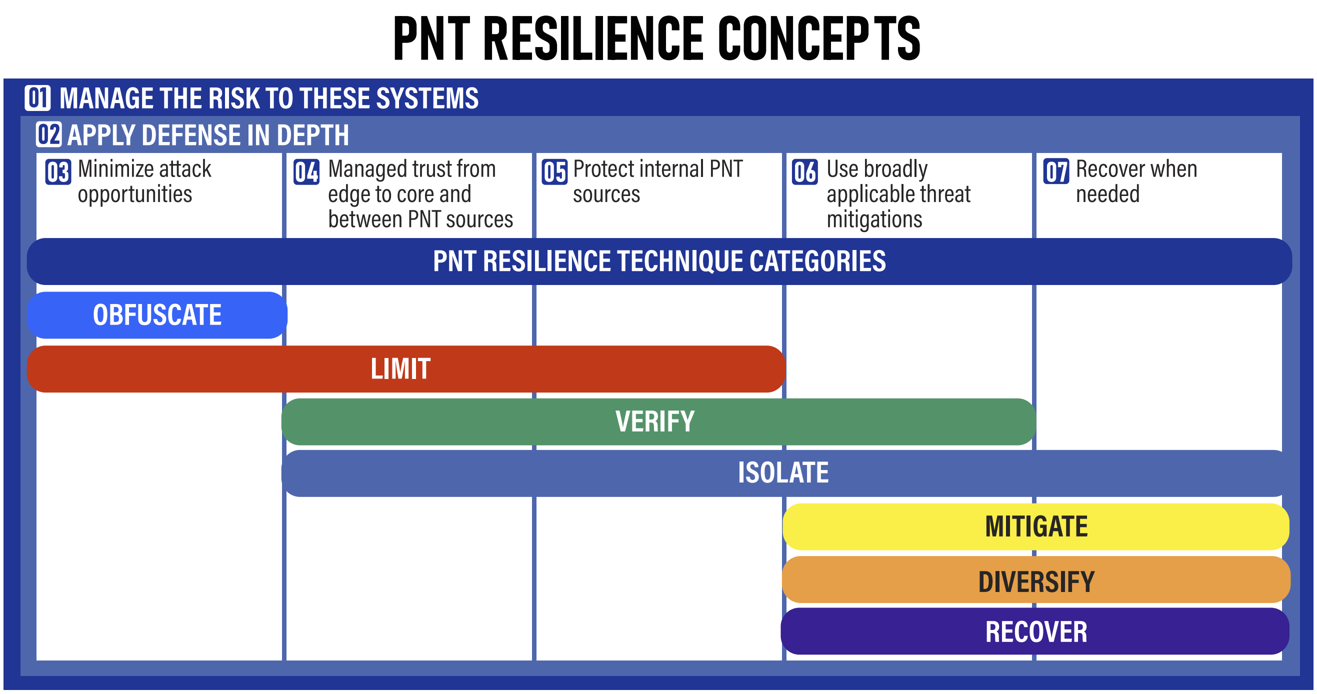


Figure 14: DHS's PNT Resilience Concepts (Credit DHS and DOT)

29 See https://www.whitehouse.gov/briefing-room/presidential-actions/2024/04/30/national-security-memorandum-on-critical-infrastructure-security-and-resilience/ and https://www.whitehouse.gov/briefing-room/statements-releases/2021/07/28/national-security-memorandum-on-improving-cybersecurity-for-critical-infrastructure-control-systems/.

30 See https://www.dhs.gov/science-and-technology/publication/resilient-pnt-reference-architecture.

31 Ibid, pg.4.

Zero Trust Architecture

As defined by NIST, a zero trust architecture assumes no implicit trust granted to assets or users based solely on who the user is, who the asset owner is, or where they are located (i.e., within a secure operations center). Digital authentication, validation, and authorization are key tools that are applied in a continuous fashion to move protection from being a static, network-based defense to a set of vigilant strategies that apply throughout an enterprise or ecosystem.[32] In looking to create the next generation of resilient PNT, the zero trust concept can be adapted to PNT to manage PNT information in a controlled and deliberate way both within the PNT user equipment system and at external interfaces.

A zero trust architecture concept is based on the principle of

Never Trust and Always Verify

Secure-By-Design and Secure-By-Default

The concepts of secure-by-design and secure-by-default are fundamental to cybersecurity and help create a focus on addressing cybersecurity risks during the technology and software manufacturers product design, development, and testing processes. These risks include, primarily, compromising a network, an operating system, or a particular software application (e.g., with ransomware), and/or compromising users (e.g., phishing attacks or denials of service). Because PNT systems that rely on signals-in-space to determine position or perform time transfer have a larger attack surface, these risks further include the manipulation of the ranging signal structures or delays. Such attacks are dangerous as they can be successfully performed without compromising the on-board software and operating systems, network data, or infrastructure, and without gaining access to devices.

Definitions by the DHS Cybersecurity and Infrastructure Security Agency (CISA), as well as international partners from Australia, Canada, the United Kingdom, Germany, the Netherlands, and New Zealand include:

- "Secure-by-Design" means that technology products are built in a way that reasonably protects against malicious cyber actors successfully gaining access to devices, data, and connected infrastructure. Secure-by-design addresses cybersecurity risks at each layer of the product design and development process as opposed to "bolting on" cybersecurity later. Thus, platforms and products contain a more holistic approach to security based on the manufacturers' risk assessments to identify and enumerate prevalent cyber threats to critical systems, and then include protections in product blueprints that account for the evolving cyber threat landscape. Secure information technology development practices and multiple layers of defense—known as defense-in-depth—

32 Summarized from https://www.nist.gov/publications/zero-trust-architecture.

are also recommended to prevent adversary activity from compromising systems or obtaining unauthorized access to sensitive data.

- Secure-by-Default products are resilient against prevalent exploitation techniques out of the box—thus protecting against the most prevalent threats and vulnerabilities without end-users having to take additional steps to secure them. A secure configuration becomes the default baseline and Secure-by-Default products automatically enable the most important security controls. Customers are made aware that when they deviate from safe defaults, they are increasing the likelihood of compromise unless they implement additional compensating controls.

Cybersecure PNT

All three of these cybersecurity concepts—Zero Trust Architectures, Secure-by-Design, and Secure-by-Default—offer a holistic approach to incorporating cyber resiliency into PNT individual components, their interactions with each other, and how they are integrated into a whole overall PNT ecosystem to produce resilient and cybersecure outcomes focused on mitigating and diminishing threats and disruptions.[33]

Examples of the application of these concepts to the extended attack surface for a PNT system include detecting jamming and spoofing signals by monitoring the automatic gain control (AGC) at the receiver front end; ephemeris signal validation; direction of arrival checking (using dual antennae); or signal authentication, where applicable. Mitigation of attacks that can be integrated into product design include antenna techniques such as fixed or controlled reception antenna patterns.

Critical Initiatives to Address PNT Cybersecurity

- Apply the NIST PNT Cybersecurity profile to transportation systems sector applications and partner with the interagency to more broadly address other critical infrastructure systems.
- In coordination with DHS, conduct testing on cyber vulnerabilities of the transportation systems sector to PNT disruptions.
- Foster PTAA principles with industry to encourage designing and building cybersecurity into their technologies, systems applications, and user devices, utilizing the NIST CSF PNT Profile and the zero trust, secure-by-design, and secure-by-default concepts.
- Monitor and detect PNT cyberattacks on civil PNT Services in coordination with DOD, DHS, and DOC and other relevant agencies:
  - Implement Federal and facilitate State, local, and commercial capabilities to monitor, identify, locate, and attribute space-based PNT service disruptions and manipulations.
  - Develop and maintain capabilities and procedures for civil contingency responses to ensure continuity of operations in the event of PNT disruptions.

33 See https://www.dhs.gov/sites/default/files/2022-06/22_0609_st_resilient_pnt_ra.pdf.

Goal 4

Ensure Spectrum Availability and Protection for PNT Services

Vision

Spectrum, free from harmful interference, is available to reliably transmit PNT services and enable mission-critical and safety-of-life applications used within:

- All modes of transportation including aviation, space, maritime, rail, emergency response, commercial trucking, and highly automated transportation applications.
- Additional Civil applications and services that rely upon PNT data, including surveying, precision agriculture, machine control, scientific applications, the energy and power grid, telecommunications, financial transactions, and health applications.
- New and emerging advanced innovations in PNT.

Strategic Goal Objective

To ensure spectrum availability for current and future PNT capabilities and protect PNT services from harmful interference, including implementation of a nationwide automated Interference Detection and Mitigation (IDM) capability.

Desired Outcomes

Spectrum is available to support PNT systems reliably, providing PNT data and signals free from harmful interference.

Interference, detection, location, and mitigation capabilities for spectrum protection are implemented for spectrum that is dedicated for PNT services. Federal, State, local, and commercial organizations have the capability to monitor, identify, locate, and attribute space-based PNT service disruptions and manipulations within the U.S. with a clear interagency reporting process, allowing the USG to be immediately aware of any interference to PNT services.

Radio frequency spectrum is considered one of "our Nation's most important national resources."[34] To promote innovation and U.S. leadership in wireless technologies, the Biden-Harris Administration launched an effort to create cooperation among Government agencies and the private sector to effectively utilize existing spectrum, identify future spectrum needs and requirements, and implement a plan to study and repurpose spectrum. This effort is recently documented in a Presidential Memorandum titled **Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy (NSS).**[35]

The goal of the NSS is to envision how to balance spectrum use of the future in a manner that enables today's advances in U.S. innovation, connectivity, and competition benefiting all Americans, while protecting sufficient access to the radio spectrum for national security, public safety, competitive next-generation communications, and scientific discovery. DOT is participating in the implementation of the NSS along with other Federal Departments and Agencies.

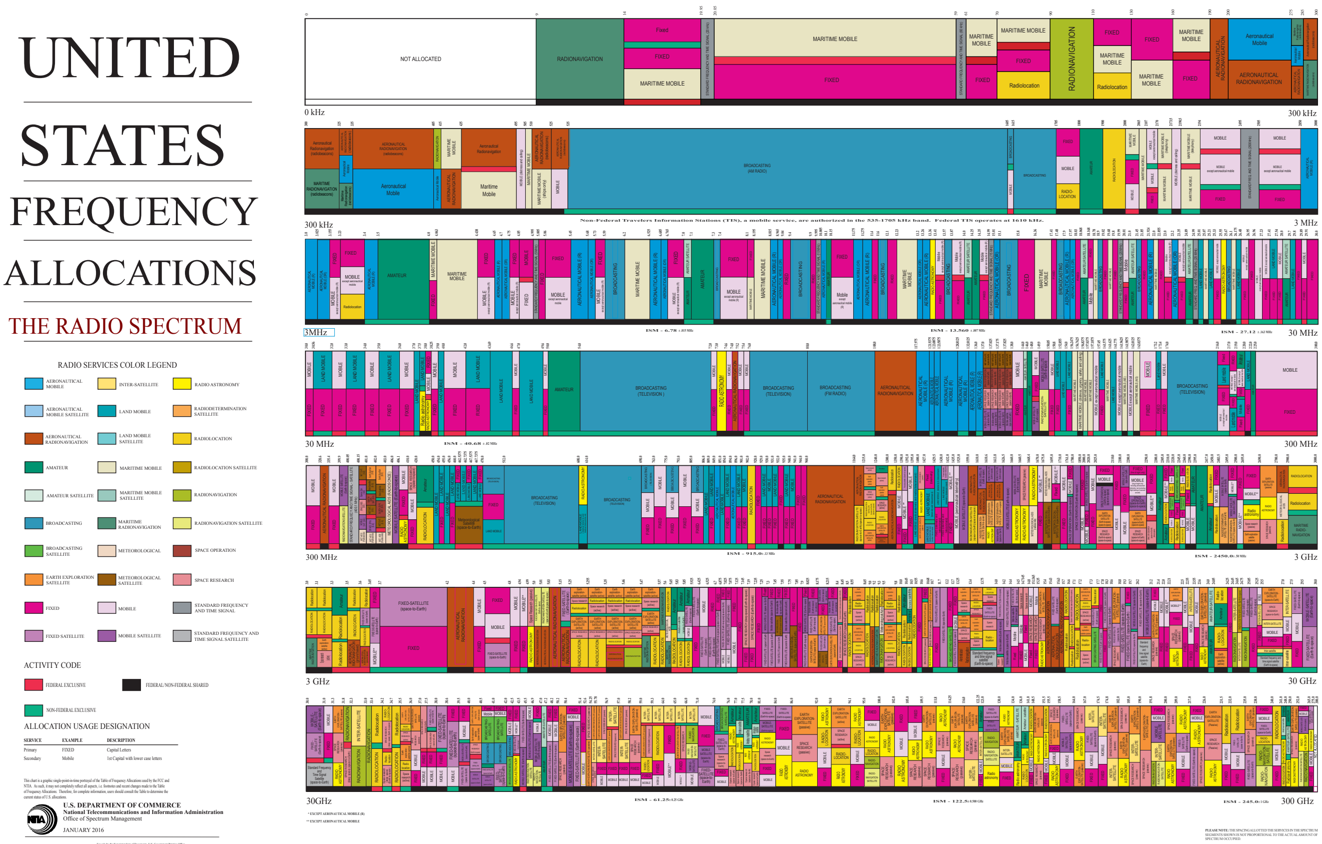


Figure 15: U.S. Frequency Allocations (Credit NTIA)[36]

34 As per President Joseph R. Biden. See https://www.ntia.gov/issues/national-spectrum-strategy.

35 See https://www.ntia.gov/report/2023/national-spectrum-strategy-pdf.

36 See https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf.

Protecting Spectrum and Ensuring Spectrum Availability for PNT

Radio frequency spectrum is used to perform a wide range of consumer, military, strategic, and vital operations, including the transmission of PNT signals. As noted in a 2022 report from the National Academies of Sciences, Engineering, and Medicine (NASEM), these services "...are vital to the modern economy and to national defense operations. ...Interference...can potentially lead to degraded performance or loss of operations."[37]

As defined by the U.S. Code of Federal Regulations, harmful interference "...endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations."[38] As noted in the NASEM report, "Given that there is greater likelihood of loss of life or property when a radionavigation or safety service is interfered with, the threshold conditions for Harmful Interference are lower than those for other radiocommunication services."

A set of three radio frequency bands, known as the "L" bands, are allocated to Radionavigation Satellite Services (RNSS) in the U.S. They include the GPS signals: L1 C/A and L1C, centered at 1575.42 MHz; L2, centered at 1227.60 MHz; and L5, centered at 1176.45 MHz, as illustrated in Figure 16. L-Band radio waves travel long distances and penetrate clouds, fog, and vegetation, making them useful for satellite communications and positioning, navigation, and timing services, as well as precise geolocation and timing information. L-Band users include private satellite

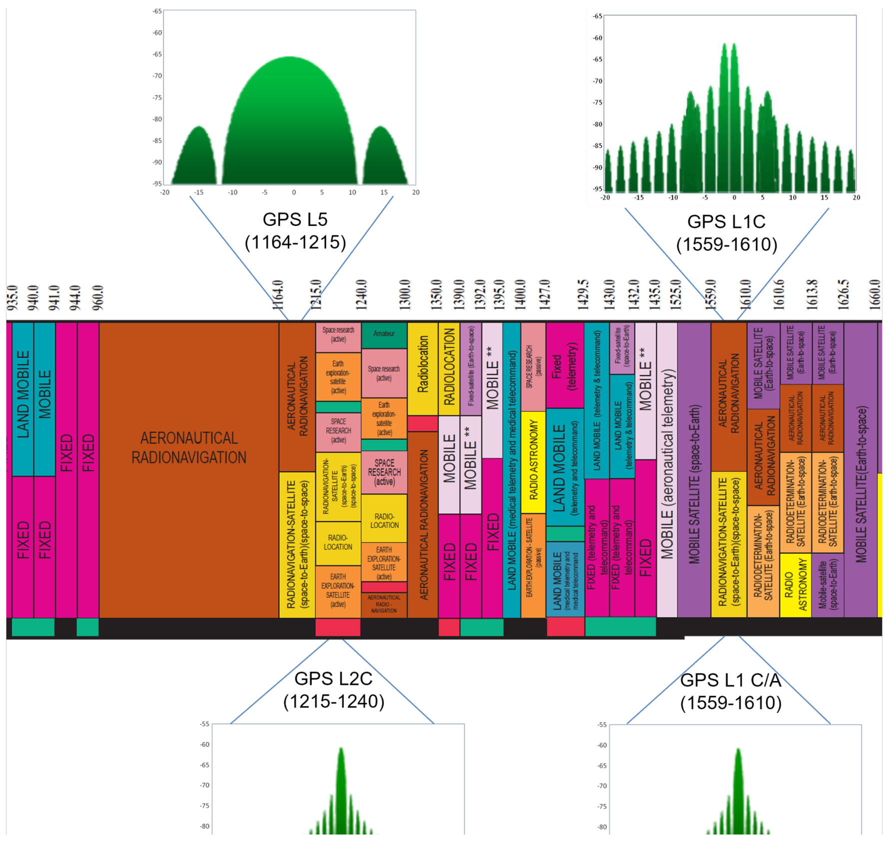


Figure 16: Image of the Dedicated L-Bands in the Radio Frequency Spectrum (Credit DOT)

37 Analysis of Potential Interference Issues Related to FCC Order 20-48, National Academies of Sciences, Engineering, and Medicine at https://nap.nationalacademies.org/catalog/26611/analysis-of-potential-interference-issues-related-to-fcc-order-20-48.

38 Code of Federal Regulations, Title 47 Chapter I Subchapter D Part 97 Subpart A § 97.3 at: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-D/part-97/subpart-A/section-97.3.

communications operators, space agencies in various countries, DOD, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and private telecommunication service providers, among others.[39]

While portions of the L-Bands are reserved for RNSS, the remainder of the L-Band spectrum is used in adjacent channels by other services, for instance, mobile satellite services, radar, and terrestrial aviation navigation systems. Given the proximity of these operations, it is critical to ensure the safe coexistence of these various uses and, in particular, that the L-Bands are free from harmful interference to preclude situations such as reduced position accuracy, an increase in the degradation of the availability of high-precision position solutions (or precludes those solutions), an inability to acquire new signals, or an inability to perform receiver autonomous integrity monitoring (RAIM).

In addition, while activities for protection of spectrum that deliver PNT signals is predominantly focused on the L-Band spectrum, with new CPNT solutions coming into use, ensuring availability of spectrum will be needed to provide reliability and integrity of the PNT signals using these different communications bands (i.e., cellular, microwave, Wi-Fi, and others), including a method for automatically identifying and mitigating threats and attacks.

Interference Detection and Mitigation

DOT participates in a five partner (P5) interagency organization designed to work with commercial owners and operators to attribute and resolve systems interference affecting users and critical infrastructure. The partners include the USCG Navigation Center (NAVCEN), the U.S. Space Force (USSF) GPS Warfighter Collaboration Cell (GWCC), the FAA Wide Area Augmentation System (WAAS), the DHS's CISA, and the Federal Communications Commission (FCC) Public Safety and Homeland Security Operations Center (FCCOPCEN). This partnership is working to develop a new, significant tool—a dedicated system-of-systems technology for the automated monitoring of PNT and GPS interference signals to improve faster resolution of incidents. The DOT PNT and Spectrum Management Program has the lead within the Department to establish the implementation of advanced automation tools, techniques, and concepts to increase PNT resiliency as part of an emerging IDM system.

39 See https://crsreports.congress.gov/product/pdf/IF/IF11558.

The interagency partners share common needs—to respond to key Federal directives (i.e., Space Policy Directive 7 (SPD-7, specifically, Section 7(d)(viii)) and EO 13905)[40] and to respond quickly to PNT disruptions, notably to:

- Detect—Develop automation technologies to detect and validate interference to PNT and manage risk to systems, assets, data, and capabilities and support effective reporting to focus and prioritize interagency information sharing in a manner consistent with management strategy and mission-critical business needs.
- Analyze—Implement appropriate interference analytical techniques to ensure the delivery of verified actionable responses; in particular, to support high confidence estimation of the geographical areas of interest (AOI) related to impacts of PNT service degradation events. It is expected that AI neural algorithms and machine learning (ML) over time will enhance, speed up, and support human analysis and decision-making. New aviation, maritime, and roadway vehicle advanced sensor systems are anticipated to generate significantly large data sets for AI to process, which would include data on recurring and non-recurring interference. AI systems can quickly scale to handle these large data sets and their metrics to reveal trends and insights not readily apparent to the human analyst to speed resolution of interference problems.
- Locate—Sense and identify the precise estimation of geolocation solutions of potential disrupting signal sources, and enable the timely actionable response for discovery of GPS-based PNT service disruption events.
- Response—Take action to deploy personnel following a detected signal disruption event and support the ability to quickly deploy and minimize the impact of the disruption event. This may include providing the triggers to transfer to a CPNT service while the GPS services are restored, creating a new level of resiliency for PNT services.
- Mitigation—Execute enforcement and compliance for resilience and restore any service degradations that were impaired due to a disruption event, thus supporting timely recovery to normal operations. Implementation of cybersecurity and resiliency mitigations will support protection of spectrum and assurances of availability, especially with regard to malicious use of the spectrum (i.e., denial of service attacks, etc.).

These five functions comprise the high-level, strategic components of an IDM initiative.

40 The DOD also follows the Joint Spectrum Interference Resolution (JSIR) Procedures based on CICSM 3320.02E at https://www.jcs.mil/Portals/36/Documents/Library/Manuals/CJCSM%203320.02E.pdf.

These efforts will help DOT improve the IDM posture with the goal of restoring GPS-based PNT services to the expected levels of availability and reliability, contributing to an overall resilient PNT services posture. It is further expected that these IDM solutions are likely applicable to a much wider cross-section of critical infrastructure operations, thus serving as an early pathfinder for added PNT resilience in and throughout the civil and transportation environments.

Critical Initiatives to Ensure Spectrum Availability and Protection for PNT Services

- Coordinate with Federal Departments and Agencies to protect the radio frequency spectrum used by GPS and its augmentations from harmful interference.
- Engage in spectrum planning, including participation in implementation of the National Spectrum Strategy released in November 2023.
- Identify spectrum needs and perform analysis and testing for satellite (LEO, MEO, and geostationary equatorial orbit [GEO]) and terrestrial PNT solutions.
- Ensure, through analysis and ongoing performance monitoring, that new, adjacent spectrum allocations do not cause interference to PNT services.
- Develop performance monitoring and interference detection and location for civil PNT services (space-based PNT and terrestrial CPNT radionavigation services) that include:
  - Monitoring, localization, and attribution of interference.
  - Establishing Government partnerships to develop an automated IDM capability including advanced automation tools, techniques, and concepts to increase PNT resiliency as part of an emerging IDM system.
  - Creating a Nationwide IDM, cybersecure common operating picture for all PNT stakeholders.
- Participate in receiver performance discussions and standards-setting.
- In coordination with DHS, DOD, and DOC, support development of interagency procedures to notify the civil sectors and Federal, State, local, territorial, and tribal agencies when space-based PNT services have anticipated disruptions.

Goal 5

Lead U.S. Civilian PNT Coordination

Vision

Through leadership in national planning and execution, civil PNT user needs are translated into requirements for PNT services in support of safety, system resiliency and cybersecurity, economic strength and global competitiveness, equity, and climate and environmental sustainability.

Strategic Goal Objective

Lead U.S. civilian PNT coordination and participate in the national and international planning and execution activities with U.S. Government Departments and Agencies, as well as interacting with industry stakeholders and users. Engage with international GNSS providers to ensure compatibility and encourage interoperability with likeminded Nations, promote transparency in civil service provision, and enable market access for United States industry.

Desired Outcomes

DOT operating administrations and other Federal Government Department and Agency stakeholder's needs are recognized and incorporated into PNT planning and execution and advancements in research and development by academia and private sector partners are fostered and leveraged appropriately.

Civil PNT Coordination and Leadership

The Secretary of Transportation has overall leadership responsibility for civil PNT matters within DOT, promulgates PNT plans that affect multiple modes of transportation (including intermodal), and collaborates with agencies outside of the Department on non-transportation civil uses of PNT systems. Figure 17 illustrates the structure of DOT coordination for civil uses of PNT systems in addition to transportation.

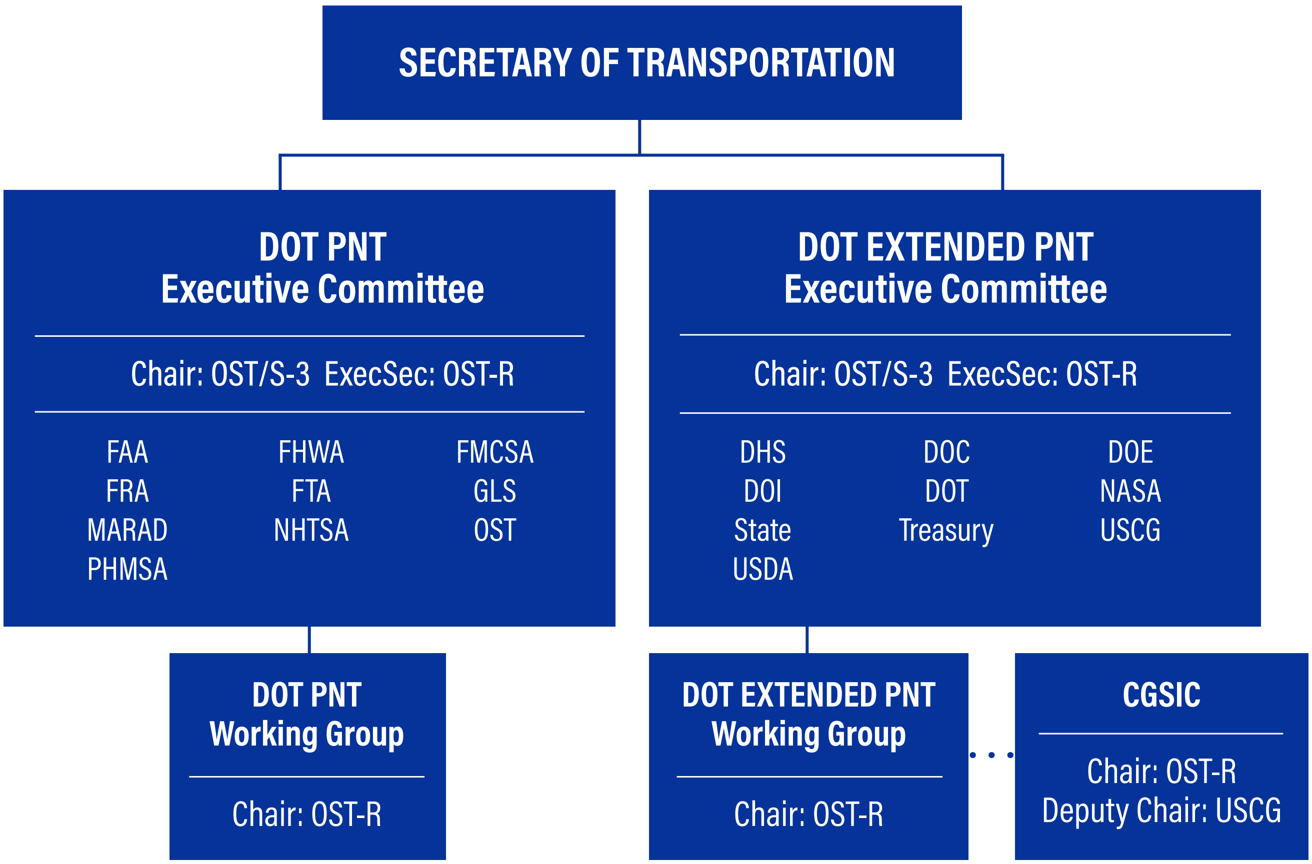


Figure 17: Civil PNT Coordination (Credit DOT)

The DOT PNT and Spectrum Management Program coordinates the development of departmental positions on PNT and Spectrum Policy to ensure safety, mobility, and efficiency of the transportation network. In addition, the Spectrum Management Program plays a key role in civil PNT systems and policy analysis and coordination for all Federal civil Departments and Agencies, representing those agencies in the development, acquisition, management, and operations of GPS. The Program also leads the Department's broad responsibilities on PNT matters with a special focus on protection of PNT systems from harmful interference, developing GPS civil requirements, coordinating civil PNT funding, and coordinating CPNT activities, including vulnerability and assessment of CPNT technologies and implementation of the DOT CPNT Action Plan. Given the breadth and scope of these institutional activities, coordination is critical. To be successful, the PNT team seeks to harness the combined intellect of industry, academia, and the public sector.

Because use of PNT crosses borders, this coordination extends to international coordination. To support cross-border and international services, numerous initiatives are coordinated among partnering nations focused on vital interoperability and security, technology research and advancements, performance and safety testing, the institutional establishment of multinational agreements, international harmonization of standards, and ongoing monitoring and operations. Coordination with international governments and organizations can improve the resilience of infrastructure around the world and can also help ensure the U.S. expands its PNT resilience knowledge base at a faster rate.

PNT Standards

PNT plays dual roles—it is a critical technology, and it is also a key enabling element in many critical and emerging technologies.

As operating environments grow more complex, standards play a role in helping to ensure safe and effective operations, as well as enhance PNT capabilities with greater resiliency. Standards also support implementation of current regulations as well as provide a path for meeting requirements associated with responsible use of PNT systems. In addition, standards create opportunities for interoperability for PNT services and national/international coordination to support the performance, standardization, and cost minimization of user equipment.

As noted in the recent National Standards Strategy for Critical and Emerging Technology (NSS CET), *"Strength in standards development has been instrumental to the United States' global technological leadership. Standards development underpins economic prosperity across the country and fortifies U.S. leadership in the industries of the future at the same time. Bolstering U.S. engagement in standards for critical and emerging technology (CET) spaces will strengthen U.S. economic and national security."*[41]

As noted in the DOT CPNT Action Plan, the transportation sector has some of the most stringent performance requirements in terms of accuracy, integrity, continuity, availability, and reliability for PNT services. Consequently, developing system requirements that focus on safety and resilience will allow determination of which requirements are currently met, and which requirements may require further commercial innovation.

41 See https://www.whitehouse.gov/wp-content/uploads/2023/05/US-Gov-National-Standards-Strategy-2023.pdf.

DOT participates in voluntary, industry consensus-based standards development working groups. Participation helps ensure that standards account for public sector civil PNT requirements, threat models, and technical and operational factors. Participation also helps to identify when PNT capabilities evolve, and how the standards need to evolve as well. This form of open standards collaboration promotes private-sector innovation and commercial product development.

The diversity and evolution of transportation and critical infrastructure applications leads to varied levels and types of specifications. PNT performance needs and constraints drive the choice and applicability of any PNT solution—these needs and constraints are different for aviation, rail, maritime, and on-road vehicles. Some of these constraints include environmental conditions, relevant dynamic variables and their required safety bounds, path predictability stipulating the geographic deployment configuration of a PNT complementary service, and standards and design constraints governing particular operating modes and use cases within a mode of transportation.

Due to such varied PNT constraints and needs, a tractable approach is multi-focused:

- Develop PNT specifications
- Participate in PNT standards development
- Identify PNT solutions for testing using an evaluation framework; and promote industry and consumer adoption based on mode, use case, and/or scenarios.

Part of informing and supporting such standards work includes producing publications on resiliency requirements and empirical assessments of system performances under nominal and threat conditions relevant to target applications. The key government and industry-driven standards participation and monitoring include:

- National Institute of Standards and Technology, via NISTIR 8323
- EO 13905 directives
- Institute of Electrical and Electronics Engineers (IEEE) P1952
- SAE (formerly the Society of Automotive Engineers) V2X Core Technical Committee
- 3rd Generation Partnership Project (3GPP) for development of 5G/6G/next G cellular telecommunications specifications
- International Civil Aviation Organization (ICAO), International Maritime Organization (IMO), and RTCA (formerly the Radio Technical Commission for Aeronautics) for standards products relating to PNT resilience
- International Telecommunications Union (ITU) timing and synchronization standards
- Other bodies that take up standards development for PNT resilience.

An important step to improving PNT resilience is to raise the bar by assembling a PNT standards framework that supports private-sector testing and evaluation of their products throughout the development process. This framework can result from harmonizing EO 13905 directed products based on the NISTIR 8323 PNT Profile and PNT contract language, as well as applying the PTAA principle strategy. In addition, the application-specific requirements can be synthesized and incorporated from existing and evolving standards as well as using relevant scenario use cases where standards are lacking.

Past and ongoing efforts supporting requirements and resiliency standards include the CPNT 2020 Demonstration analysis and results, the framework development and testing for automated vehicles PNT systems, participation in the IEEE 1952p working group, as well as analysis and testing of live sky PNT threat scenarios. Future application-specific research efforts will be focused on leveraging this work to inform PNT technical and resiliency standards for intelligent transportation systems, connected automated vehicles, unmanned aircraft systems (UAS), rail, and maritime systems and technologies.

Workforce Development

Workforce development focuses on two critical audiences—existing professionals and workers who need to keep current on the state-of-the-practice; and the next generation workforce studying at technical schools, vocational schools, colleges, and universities.

DOT supports workforce development for both audiences:

- For current professionals, best practices, guidelines, test results, and other documentation is provided through webinars and conferences.
- In training the next generation, grants provided to UTCs are structured to engage students in the research and to promote the use of research materials and standards in classroom settings.[42]

Critical Initiatives for U.S. Civil PNT Coordination

- Co-chair the National Space-Based PNT EXCOM, which is the interagency body for guiding whole-of-government interests in the provision of space-based PNT services and augmentations, PNT resiliency, and the adoption of CPNT capabilities.
- Represent DOT in Federal radionavigation planning and requirements development activities, including development of the FRP in partnership with DOD and DHS to reflect the policy, planning, and requirements development activities for present and future Federally provided PNT systems.
- Represent the civil Departments and Agencies in the development, acquisition, management, and operations of GPS, including providing DOT civil liaisons to U.S. Space Force Space Systems Command and Space Operations Command and a future liaison to the Pentagon.
- Chair the CGSIC with USCG Navigation Center as the Deputy Chair and Executive Secretariat.
- Chair the DOT PNT Working Group and Extended DOT PNT Working Group.
- Collaboratively analyze and address with civil Departments and Agencies and DOD how PNT, GPS, and communications systems are used for public safety and critical life-safety transportation services;

42 DOT is currently working with two UTCs focused on PNT: The Center for Automated Vehicles Research with Multimodal AssurEd Navigation (CARMEN+) at Ohio State University and The Center for Assured and Resilient Navigation in Advanced TransportatION Systems (CARNATIONS) at Illinois Institute of Technology (IIT).

and the ability to automate a nationwide interference detection capability for these systems in order to strengthen system response and recovery plans and protocols to minimize the effects of system disruptions and hasten system recovery.

- Support and nurture national and international working groups and standards development efforts and ensure that public safety service applications based on U.S. space-based PNT services meet or exceed worldwide recognized standards.
- Continue to foster PNT workforce initiatives with UTCs.
- Coordinate CPNT activities, including vulnerability and assessment of CPNT technologies and implementation of the DOT CPNT Action Plan.

CONCLUSION

PNT services are critical to the safe, secure, and efficient use of the national transportation system by the traveling public, the freight community, other commercial and private entities, as well as Federal users of the roads, rails, waterways, and airspace within the United States. PNT services are also foundational and essential throughout many, if not all, sectors of the economy.

Critical infrastructure sectors such as communications, banking, the electric grid, and dams rely on the accuracy, reliability, and resilience of PNT technologies. Both a robust set of PNT services and the adoption of those services by critical infrastructure operators is necessary to our economy, well-being, and safety.

As GPS technology advances, the number of threats to the system continue to increase. We need to protect against these threats and, at the same time, become less reliant upon GPS as the predominant source of PNT. This DOT PNT Strategic Plan underscores the importance of adopting commercially-provided sources of complementary PNT to meet growing national, homeland, and economic security requirements, and to enable diverse commercial and scientific applications. The United States is also encouraging research and development of PNT services that explore use of quantum sensing, relative navigation, and signals of opportunity.

As the civil PNT policy lead for the United States, DOT is identifying risks associated with dependence on space-based PNT and fostering responsible use approaches to PNT service acquisition, integration, and deployment across critical infrastructures. This strategic plan identifies outcomes desired for the Nation, and embraces and implements the PTAA principles for resilient and cybersecure civil PNT services, technologies, and systems.

This PNT Strategic Plan identifies strategic goals and outcomes that will result from implementing each goal area. Outcomes sought from this strategic plan include:

- The Nation and PNT users advance toward an "ideal" National PNT Architecture that continuously meets service requirements for the Nation's civil PNT needs; and ensures the U.S. is a leader in fostering the responsible use of interoperable and secure PNT services by U.S. industries that compete globally.
- The Nation achieves PNT resiliency through implementation and adoption of the principle of PTAA and works with civil users to adopt "responsible use of PNT services," incorporating the deliberate, risk-informed use of PNT into their technology decisions, procurements, and system operations. Complementary sources of PNT data are operational from new CPNT solutions that meet the timing and positioning requirements necessary to adopt into end user applications. Federal, commercial, and civil organizations establish response and recovery plans to address PNT service disruptions.

- The Nation benefits from increased PNT cybersecurity and users can trust that PNT data is safe, accurate, and reliable.
- Federal, State, local, and commercial organizations have the capability to monitor, identify, locate, and attribute PNT service disruptions and manipulations within the U.S. with a clear, interagency, collaborative reporting process that supports FCC's spectrum interference enforcement efforts.
- Civil PNT coordination ensures Federal agency needs are recognized and incorporated in planning, each Federal agency partner's contributions are integrated, and advancements and research by academic and private sector partners are leveraged appropriately.
- The National PNT Architecture and ecosystem is increasingly interoperable and secure internationally through diverse multisource PNT system-of-systems.

As the lead USG Civil Department for PNT policy, DOT will perform activities in each of the strategic goal areas to address key national policy and departmental priorities. A core strategy to accomplish this objective is stakeholder engagement and collaborative initiatives with other Federal Departments and Agencies, with the private sector and academia.

In order to realize the benefits of a resilient, innovative, and more robust PNT system, our priority is to ensure the services continue to remain safe and available to an ever-growing community of users. DOT will continue to actively advocate on behalf of the civil user community and continue to champion PNT work to protect and modernize GPS in partnership with DOD, as well as defend and advocate for these vital services. Using this PNT Strategic Plan as a basis, DOT and its strategic partners will lean into research and evaluation and facilitate adoption of CPNT technologies that push the boundary of what's possible – innovations that help us achieve our goals, grow our economy, and unlock creativity and entrepreneurship to meet current and future needs for PNT.

As there is much work ahead of us, this DOT PNT Strategic Plan and a follow-on PNT Implementation Plan are designed to be actionable to ensure robust and resilient PNT services are adopted into our Nation's critical infrastructure as expeditiously as possible.

APPENDIX

List of Acronyms

3GPP	3rd Generation Partnership Project
AAM	Advanced Air Mobility
AGC	Automatic Gain Control
AI	Artificial Intelligence
AIS	Automated Identification Systems
AOI	Areas of Interest
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
BIL	Bipartisan Infrastructure Law
CAF	Cross Ambiguity Function
CARMEN	Center for Automated Vehicles Research with Multimodal AssurEd Navigation
CARNATIONS	Center for Assured and Resilient Navigation in Advanced Transportation Systems
CET	Critical and Emerging Technology
CGSIC	Civil GPS Service Interface Committee
CISA	Cybersecurity and Infrastructure Security Agency (part of DHS)
CPNT	Complementary PNT
CORS	Continuously Operating Reference Systems
CRPA	Controlled Reception Pattern Antenna
CSF	Cybersecurity Framework
CSMS	Civil Signal Monitoring System
DHS	Department of Homeland Security
DME	Distance Measuring Equipment
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOJ	Department of Justice
DOT	Department of Transportation
EAR	Export Administration Regulations
ECDIS	Electronic Chart Display Information Systems
EO	Executive Order
ESG	Executive Steering Group
eVTOL	electric Vertical Take-off and Landing
EXCOM	National Space-Based PNT Executive Committee
FAA	Federal Aviation Administration

FCC	Federal Communications Commission
FCCOPCEN	FCC Public Safety and Homeland Security Operations Center
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FTA	Federal Transit Administration
FY	Fiscal Year
GA	General Aviation
GEO	Geostationary Equatorial Orbit
GHG	Greenhouse Gas
GIS	Geographic Information System
GIWG	GPS International Working Group
GLS	Great Lakes St. Lawrence Seaway
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GWCC	GPS Warfighter Collaboration Cell
HATS	Highly Automated Transportation Systems
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
IDM	Interference Detection and Mitigation
IEEE	Institute of Electrical and Electronics Engineers
ILS	Instrument Landing System
IMO	International Maritime Organization
IMU	Inertial Measurement Unit
ISM	Integrity Support Message
IoT	Internet of Things
ISECG	International Space Exploration Coordination Group
ITAR	International Traffic in Arms Regulations
ITS	Internet Time Service
ITS	Intelligent Transportation Systems
ITU	International Telecommunications Union
KG	Kilograms
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
LF	Low Frequency

MARAD	Maritime Administration
MEO	Medium Earth Orbit
MF	Medium Frequency
ML	Machine Learning
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NATO	North Atlantic Treaty Organization
NAVCEN	U.S. Coast Guard Navigation Center
NDB	Nondirectional Beacon
NIST	National Institute of Standards and Technology
NISTIR	National Institutes of Standards and Technology Internal Report
NOAA	National Oceanic and Atmospheric Administration
NPEF	National Space-Based PNT Systems Engineering Forum
NRCS	Natural Resources Conservation Service
NRMC	National Risk Management Center
NSRS	National Spatial Reference System
NSS	National Spectrum Strategy
NTIA	National Telecommunications and Information Administration
OST	Office of the Secretary of Transportation
OSTP	Office of Science, Technology, and Policy (Executive Office of the President)
OST-R	Office of the Assistant Secretary for Research and Technology
PBN	Performance-Based Navigation
PHMSA	Pipeline and Hazardous Materials Safety Administration
PNT	Positioning, Navigation, and Timing
PTA	Protect, Toughen, and Augment
PTAA	Protect, Toughen, Augment, and Adopt
PTC	Positive Train Control
PTP	Precision Time Protocol
PVT	Position, Velocity, and Time
RAIM	Receiver Autonomous Integrity Monitoring
RD&T	Research, Development, and Technology
RF	Radio Frequency
RNSS	Radionavigation Satellite Services
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers

SBIR	Small Business Innovation Research
SPD-7	Space Policy Directive 7
STAP	Space-Time Adaptive Processing
State	Department of State
TACAN	Tactical Air Navigation
TRACON	Terminal Radar Approach Controls
Treasury	Department of the Treasury
TRL	Technology Readiness Level
TSA	Transportation Security Administration
TSS	Transportation Systems Sector
TWSTT	Two-Way Satellite Time Transfer
UAS	Unmanned Aircraft Systems
UHF	Ultra-High Frequency
UKC	Under Keel Clearance
USC	United States Code
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USG	United States Government
USGS	United States Geological Survey
USSF	United States Space Force
UTC	Coordinated Universal Time
UTC	University Transportation Center
UWB	Ultra-Wideband
V2X	Vehicle-to-Everything Communications
VHF	Very High Frequency
Volpe Center	John A. Volpe National Transportation Systems Center (part of DOT)
VOR	Very High Frequency Omnidirectional Range Station
VRU	Vulnerable Road User
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 1984
WWV	Time signal radio station near Fort Collins, Colorado operated by NIST
WWVB	Time signal radio station near Fort Collins, Colorado operated by NIST
WWVH	Time signal radio station near Kauai, Hawaii operated by NIST

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