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Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing (PNT) Services

Michael Bartock
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Michael Bartock
Suzanne Lightman
Computer Security Division
Information Technology Laboratory

Karen Reczek
Standards Coordination Office
Laboratory Programs

Ya-Shian Li-Baboud
Software Systems Division
Information Technology Laboratory

Joseph Brule
National Security Agency
Ft. Meade, MD

James McCarthy
Applied Cybersecurity Division
Information Technology Laboratory

Doug Northrip
Arthur Scholz
Theresa Suloway
The MITRE Corporation
McLean, VA

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National Institute of Standards and Technology
Attn: Applied Cybersecurity Division, Information Technology Laboratory
100 Bureau Drive (Mail Stop 2000) Gaithersburg, MD 20899-2000
Email: mailto: pnt-eo@list.nist.gov

Reports on Computer Systems Technology

The Information Technology Laboratory (ITL) at the National Institute of Standards and Technology (NIST) promotes the U.S. economy and public welfare by providing technical leadership for the Nation's measurement and standards infrastructure. ITL develops tests, test methods, reference data, proof of concept implementations, and technical analyses to advance the development and productive use of information technology. ITL's responsibilities include the development of management, administrative, technical, and physical standards and guidelines for the cost-effective security and privacy of other than national security-related information in federal information systems.

Abstract

The national and economic security of the United States (US) is dependent upon the reliable functioning of the nation's critical infrastructure. Positioning, Navigation, and Timing (PNT) services are widely deployed throughout this infrastructure. In a government wide effort to mitigate the potential impacts of a PNT disruption or manipulation, Executive Order (EO) 13905, *Strengthening National Resilience Through Responsible Use of Positioning, Navigation and Timing Services* was issued on February 12, 2020. The National Institute of Standards and Technology (NIST) as part of the Department of Commerce (DoC), produced this voluntary PNT Profile in response to *Sec.4 Implementation (a),* as detailed in the EO. The PNT Profile was created by using the NIST Cybersecurity Framework and can be used as part of a risk management program to help organizations manage risks to systems, networks, and assets that use PNT services. The PNT Profile is intended to be broadly applicable and can serve as a foundation for the development of sector-specific guidance. This PNT Profile provides a flexible framework for users of PNT to manage risks when forming and using PNT signals and data, which are susceptible to disruptions and manipulations that can be natural, manufactured, intentional, or unintentional.

Keywords

critical infrastructure; Cybersecurity Framework; Executive Order; GPS; GNSS; navigation; PNT; positioning; risk management; timing.

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Supplemental Content and Potential Updates

Any potential updates for this document that are not yet published in an errata update or revision—including additional issues and potential corrections—will be posted as they are identified; see the NISTIR 8323 publication details.

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Executive Summary

Executive Order 13905, *Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing (PNT) Services*, was issued on February 12, 2020 [EO 13905]. It seeks to protect the national and economic security of the United States from the disruption or manipulation of systems that form or use PNT data and information vital to the functioning of U.S. critical infrastructure and technology-based industries. The Executive Order (EO) directs the Department of Commerce to develop a PNT Profile that will address the four components of responsible use of PNT, as stated in the EO:

1. Identify systems that use or form PNT data.
2. Identify PNT data sources.
3. Detect disruption and manipulation of the systems that form or use PNT services and data.
4. Manage risk regarding responsible use of these systems.

The PNT Profile provides a flexible framework for users of PNT services to manage risks when forming and using PNT signals and data, which are susceptible to disruptions and manipulations that can be natural, manufactured, intentional, and unintentional. It was created by applying the NIST Cybersecurity Framework (CSF) [NIST CSF] and can be applied to all organizations that use PNT services, irrespective of the level of familiarity or knowledge that they have with the CSF. Organizations that have fully or partially adopted, or who have not adopted the CSF can benefit.

The PNT Profile is voluntary and does not: issue regulations, define mandatory practices, provide a checklist for compliance, or carry statutory authority. It is intended to be a foundational set of guidelines. Sector-specific agencies (SSAs) and entities may wish to augment or further develop their own PNT cybersecurity efforts via full or partial implementation of the recommended practices in this document. Any implementation of its recommendations will not necessarily protect organizations from all PNT disruption or manipulation. Each organization is encouraged to make their risk management decisions in the context of their own cyber ecosystem, architecture, and components. The PNT Profile's strategic focus is to supplement preexisting resilience measures and elevate the postures of less mature initiatives.

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1 PNT Profile: Introduction

Executive Order 13905 (EO 13905), *Strengthening National Resilience through Responsible Use of Positioning, Navigation, and Timing Services*, was issued on February 12, 2020 [EO 13905]. It seeks to help organizations protect themselves from the disruption or manipulation of positioning, navigation, and timing (PNT) services, particularly those organizations whose use of PNT services are vital to the functioning of U.S. critical infrastructure. EO 13905 directs the Department of Commerce to develop a PNT Profile for users of PNT services.

1.1 Purpose and Objectives

The PNT Profile is designed to be used as part of a risk management program in order to help organizations manage risks to systems, networks, and assets that use PNT services. The PNT Profile provides guidance for establishing risk management approaches to achieve the desired outcomes commensurate with acceptable and responsible levels of risk that result from the disruption or manipulation of PNT data. The PNT Profile is not intended to serve as a solution or compliance checklist that would guarantee the responsible use of PNT services.

Use of the PNT Profile will help organizations:

- Identify systems that use PNT services and determine their operating and performance requirements;
- Identify sources of PNT data;
- Identify known and anticipated threats to PNT services, equipment, and data;
- Protect systems that are dependent on PNT services by adhering to basic principles of responsible use;
- Detect disruptions and manipulation of PNT services and data;
- Address risk in the management and use of PNT services and data;
- Respond to PNT service or data anomalies in a timely, effective, and resilient manner; and
- Recover from PNT service or data anomalies in a timely, effective, and resilient manner.

1.2 Scope

The PNT Profile's scope includes systems that use PNT services, including systems that consume and then rebroadcast PNT data for consumption by other organizational entities where a PNT service is defined as "any system, network, or capability that provides a reference to calculate or augment the calculation of longitude, latitude, altitude, or transmission of time or frequency data, or any combination thereof" [EO 13905]. PNT service providers include government systems, such as Global Positioning Systems (GPS), public NIST Network Time Protocol (NTP) servers, commercial services, and internal systems. The PNT Profile's scope does not include source PNT signal generators and providers (e.g., a Global Navigation Satellite System (GNSS) control segment or space segment, as shown in **Figure** 1).

PNT services interface with PNT systems and components operated by an organization to produce PNT data, which can take the form of position, navigation, or timing information. The responsible use of PNT services require the stakeholder to identify the dependencies of PNT data

(within their components, sub-systems, and systems), evaluate the impact should the disruption or manipulation of PNT data be realized, and manage the residual risk.

This PNT Profile defines the responsible use of PNT services as it relates to critical infrastructure and national and economic security. In this case, responsible use by organizations includes the incorporation of:

- Risk-informed management of PNT services;
- Risk-based approaches that minimize the potential effects of the disruption or manipulation of PNT services and data; and
- Deliberate planning and action regarding the secure management of PNT services.

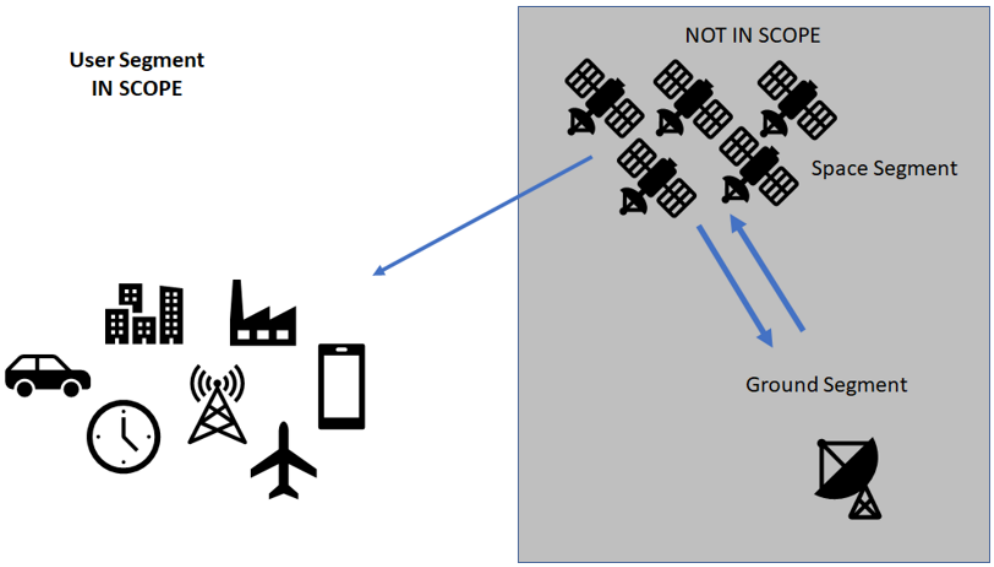

Figure 1 - Example of How the PNT Profile Applies to GNSS

The PNT Profile addresses systems and components operated by an organization to produce PNT data, which can take the form of position, navigation, or timing information. The provider (in this example, the GNSS space and ground segments) is not within the scope of the PNT Profile.

For the purposes of the PNT Profile, PNT data includes all information used by PNT equipment to form PNT solutions. This includes but is not limited to signals, waveforms, network packets, and other means to transmit PNT information.

1.3 Audience

This document's intended audience includes:

- Public and private organizations that use PNT services;
- Managers responsible for the use of PNT services;

- Risk managers, cybersecurity professionals, and others with a role in risk management for systems that use PNT services;
- Procurement officials responsible for the acquisition of PNT services;
- Mission and business process owners responsible for achieving operational outcomes dependent on PNT services; and
- Researchers and analysts who study systems that rely on PNT and/or study the unique cybersecurity needs of PNT services.

The PNT Profile is intended for a general audience and is broadly applicable. The PNT Profile applies to organizations that:

- Have already adopted the NIST Cybersecurity Framework (CSF) to help identify, assess, and manage cybersecurity risks [NIST CSF];
- Are familiar with the CSF and want to improve their risk postures; or
- Are unfamiliar with the CSF but need to implement risk management frameworks for the responsible use of their PNT services.

2 PNT Profile: Intended Use

The PNT Profile is a flexible tool that can be used by an organization to help meet mission and business objectives that are dependent upon the use of PNT services. The PNT Profile can also help organizations determine risks based on their assessments of the potential impacts of manipulation or the disruption of PNT services to business and operational objectives. The PNT Profile is intended to help users of PNT services prioritize necessary cybersecurity activities based on business objectives. Additionally, the PNT Profile can be used to help organizations identify areas where standards, practices, and other guidance could help manage risks to systems that use PNT services. An organization can use the PNT Profile in conjunction with its systematic process for identifying, assessing, and managing risk. NIST acknowledges the existing efforts being undertaken by individual entities to address the responsible use of PNT services in their sectors. The PNT Profile is intended to complement, not replace these efforts. NIST also encourages the development of sector specific guidance if more specific risk management efforts would be required. Organizations within sectors can customize the PNT Profile by considering the following:

- What processes and assets require PNT data (direct recipient of PNT services)?
- What processes and assets are dependent on other assets that require PNT data (i.e., what are the secondary effects)?
- What processes and assets are vulnerable to the disruption or manipulation of PNT services?
- What are the integrity and availability thresholds of PNT to avoid mission impact?
- What safeguards are available?
- What is the impact to the organization should a process or asset be lost or degraded?
- What techniques can be used to detect events of concern?
- What techniques can be used to respond to events of concern?
- What techniques can be used to recover pre-event capabilities?

3 PNT Profile: Overview

3.1 Risk Management Overview

Risk management is the ongoing process of identifying, assessing, and responding to risk as related to an organization's mission objectives. To manage risk, organizations should understand the likelihood that an event will occur as well as its potential impacts. An organization should also consider statutory and policy requirements that may influence or inform cybersecurity decisions.

The PNT Profile supports and is informed by cybersecurity risk management processes. Using the PNT Profile, organizations can make more informed decisions—based on business needs and risk assessments—to select and prioritize cybersecurity activities and expenditures that help identify systems dependent on PNT, identify appropriate PNT sources, detect disturbances and manipulation of PNT services, manage the risk to these systems, and ensure resiliency.

The PNT Profile provides a flexible approach for users of PNT to manage risks when forming and using PNT signals and data regardless of the source of the risk, including natural events, malicious actions, and human activities that have unintended consequences. It also provides a starting point from which organizations can customize their approach to manage risk to their PNT services and data. A customized approach provides the most appropriate measures, processes, and prioritization of resources for the reliable and efficient functioning of critical infrastructure applications.

Organizations can use the PNT Profile in conjunction with existing risk management processes. The PNT Profile assumes that the organization implements cybersecurity risk management processes, and this Profile is intended to provide additional risk management considerations specific to PNT. Examples of cybersecurity risk management processes include International Organization for Standardization (ISO) 31000:2018, ISO/International Electrotechnical Commission (IEC) 27005:2018, and NIST Special Publication 800-39. A list of additional resources is included in Appendix C of the PNT Profile.

3.2 Cybersecurity Framework Overview

Created through collaboration between industry and government, the Cybersecurity Framework [NIST CSF] provides prioritized, flexible, risk-based, and voluntary guidance based on existing standards, guidelines, and practices to help organizations better understand, manage, and communicate cybersecurity risks. Although it was designed for organizations that are part of the U.S. critical infrastructure, many other organizations in the private and public sectors (including federal agencies) use the NIST Cybersecurity Framework.

The Cybersecurity Framework consists of three main components:[1]

1. The Framework Core provides a catalog of desired cybersecurity activities and outcomes[2] using common language. The Core guides organizations in managing and reducing their cybersecurity risks in a way that complements an organization's existing cybersecurity and risk management processes.
2. The Framework Implementation Tiers provide context for how an organization views cybersecurity risk management. The Tiers help organizations understand whether they have a functioning and repeatable cybersecurity risk management process and the extent to which cybersecurity risk management is integrated with broader organizational risk management decisions.
3. The Framework Profiles are customized to the outcomes of the Core to align with an organization's requirements. Profiles are primarily used to identify and prioritize opportunities for improving cybersecurity at an organization.

The Framework Core presents standards, guidelines, and practices within five concurrent and continuous Functions, which are described below. In the context of this "PNT Profile", a "cybersecurity event" refers to a potential for the disruption or manipulation of PNT services.

1. Identify – Develop the organizational understanding to manage cybersecurity risk to systems, assets, data, and capabilities. The activities in the Identify Function are foundational to the effective use of the Cybersecurity Framework, enabling an organization to focus and prioritize its efforts in a manner consistent with its risk management strategy and business needs.
2. Protect – Develop and implement the appropriate safeguards to ensure the delivery of critical infrastructure services. The activities in the Protect Function support the ability to limit or contain the impact of a potential PNT cybersecurity event.
3. Detect – Develop and implement the appropriate activities to identify the occurrence of a cybersecurity event. The activities in the Detect Function enable the timely discovery of PNT cybersecurity events.
4. Respond – Develop and implement the appropriate activities to take action regarding a detected cybersecurity event. The activities in the Respond Function support the ability to contain the impact of a potential PNT cybersecurity event.
5. Recover – Develop and implement the appropriate activities to maintain plans for resilience and to restore any capabilities or services that were impaired due to a cybersecurity event. The activities in the Recover Function support timely recovery to normal operations to reduce the impact of a PNT cybersecurity event.

When considered together, these Functions provide a high-level, strategic view of the life cycle of an organization's management of PNT cybersecurity risk. The Framework Core then identifies underlying Categories and Subcategories for each Function. The 108 Subcategories are

[1] Elements of the Cybersecurity Framework—including Core, Implementation Tiers, Profile, Function, Category, and Subcategory—are normally capitalized and will be capitalized throughout this document.

[2] The word "outcomes" is used because the Cybersecurity Framework (CSF) focuses on the "what" rather than the "how." In other words, the emphasis is on the cybersecurity outcomes that the organization wants to achieve rather than how they will achieve it. The References described on page 8 help organizations with the "how."

discrete cybersecurity outcomes that are organized into 23 Categories like “Asset Management” or “Protective Technology.” **Table 1** shows the Five Functions and 23 Categories of the Core.

Table 1 - Cybersecurity Framework Functions and Categories

Function Unique Identifier	Function	Category Unique Identifier	Category
ID	Identify	ID.AM	Asset Management
		ID.BE	Business Environment
		ID.GV	Governance
		ID.RA	Risk Assessment
		ID.RM	Risk Management Strategy
		ID.SC	Supply Chain Risk Management
PR	Protect	PR.AC	Access Control
		PR.AT	Awareness and Training
		PR.DS	Data Security
		PR.IP	Information Protection Processes and Procedures
		PR.MA	Maintenance
		PR.PT	Protective Technology
DE	Detect	DE.AE	Anomalies and Events

Function Unique Identifier	Function	Category Unique Identifier	Category
		DE.CM	Security Continuous Monitoring
		DE.DP	Detection Processes
RS	Respond	RS.RP	Response Planning
		RS.CO	Communications
		RS.AN	Analysis
		RS.MI	Mitigation
		RS.IM	Improvements
RC	Recover	RC.RP	Recovery Planning
		RC.IM	Improvements
		RC.CO	Communications

References are existing standards, guidelines, and practices that provide practical guidance to help an organization achieve the desired outcome of each Subcategory. An example of two Subcategories and applicable References within the Asset Management Category are shown in **Figure 2**.

Figure 2 - Cybersecurity Framework Subcategory Example

Function	Category	Subcategory	Informative References
IDENTIFY (ID)	**Asset Management (ID.AM):** The data, personnel, devices, systems, and facilities that enable the organization to achieve business purposes are identified and managed consistent with their relative importance to organizational objectives and the organization's risk strategy.	**ID.AM-1:** Physical devices and systems within the organization are inventoried	**CIS CSC** 1 **COBIT 5** BAI09.01, BAI09.02 **ISA 62443-2-1:2009** 4.2.3.4 **ISA 62443-3-3:2013** SR 7.8 **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 **NIST SP 800-53 Rev. 4** CM-8, PM-5
		ID.AM-2: Software platforms and applications within the organization are inventoried	**CIS CSC** 2 **COBIT 5** BAI09.01, BAI09.02, BAI09.05 **ISA 62443-2-1:2009** 4.2.3.4 **ISA 62443-3-3:2013** SR 7.8 **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2, A.12.5.1 **NIST SP 800-53 Rev. 4** CM-8, PM-5

The Subcategory outcomes are organized according to Functions and Categories and are not prioritized within the Core. Each organization has unique requirements, risk tolerance and resources. Therefore, the prioritization of the Subcategory outcomes will vary from one organization to the next.

The PNT Profile in Section 3.3 can be used as a foundation for building a custom profile, as shown in **Figure 3**. A custom profile can be built using the business objectives, threat environment, requirements, and controls as inputs. The outcomes associated with a custom profile based on the PNT Profile are the outcomes from the Executive Order: the identification of systems dependent on PNT services that identify appropriate PNT services, detect the disruption and manipulation of PNT services, and manage the risk to those systems.

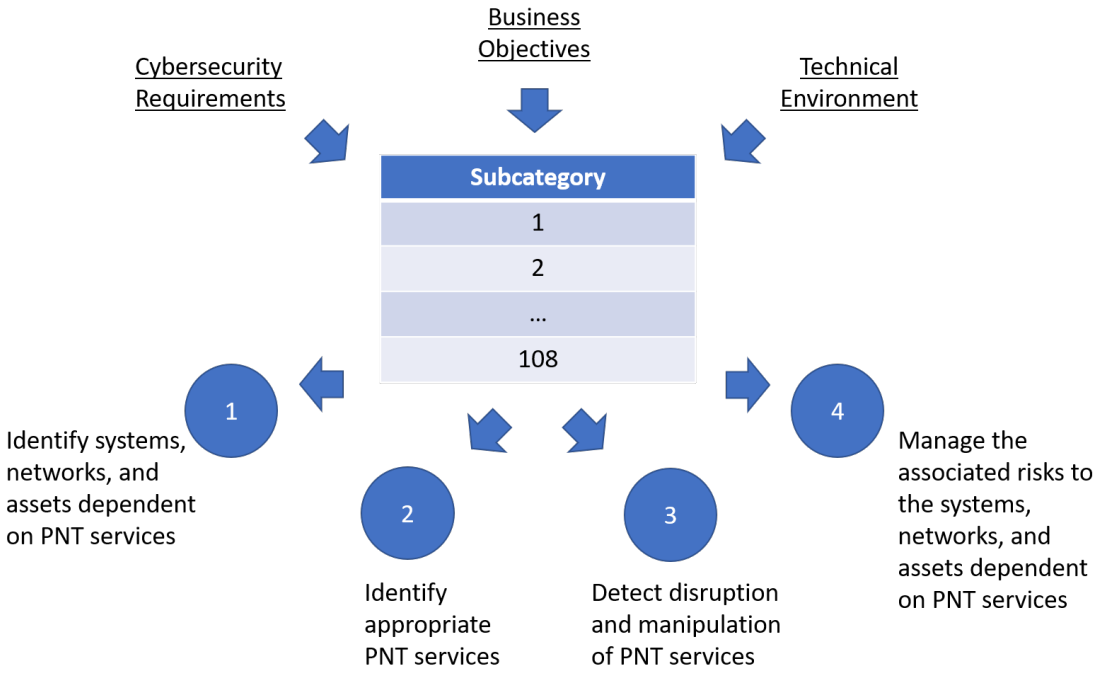

Figure 3 - PNT Profile Creation Process

Since organizations within the PNT community sector or sub-sector share many of the same business objectives and regulatory requirements, the creation of a high-level profile can provide a common starting point. The PNT Profile can make it easier for organizations to begin incorporating cybersecurity and can also be used to provide a baseline of cybersecurity for organizations within a sector or sub-sector. Individual organizations can further customize a profile by taking the sector/sub-sector profile and then tailor or augment it to address requirements, business objectives, or environmental threats unique to them.

The PNT Profile is intended to be implemented within the larger context of an organization that is developing and executing its own cybersecurity program.[3] That program should be based on

[3] See IEC 62443 2-1, ISO/IEC 27001 (security management), and NIST SP 800-39.

organizational cybersecurity risk management policies and procedures. This PNT Profile is best implemented if a cybersecurity program is in place at the organizational level. However, this caveat does not preclude any organization from implementing the PNT Profile should a cybersecurity program not be in place.

4 The PNT Profile

This section was created by using the Cybersecurity Framework, as described in Section 3.2. The tables summarize the Subcategories for a Function and a Category. The references provided in the tables include cybersecurity guidance, PNT-specific guidance, and illustrative methods to implement the guidance. It is not intended to be a comprehensive list of all PNT references (see **References**), but a sample of potentially relevant resources depending on the PNT service(s) the organizations use and their PNT service and data requirements. The references that correspond to the Subcategory may not necessarily apply to all sectors. The Categories and Subcategories defined by the Cybersecurity Framework will address different aspects of the four components identified in the Executive Order, as illustrated in Table 2. Sections 4.1 through 4.5 provide insight on how the Subcategories address the responsible use of PNT. Note: Not all Subcategories in the NIST CSF are listed here; only those most applicable to this PNT Profile Acronyms described in the PNT Profile are listed in Appendix A.

Table 2 - Mapping the EO Implementation Guidance to the Cybersecurity Framework Profile

		Identify systems dependent on PNT services	Identify appropriate PNT sources	Detect disturbance and manipulation of PNT services	Manage the risk to PNT systems
IDENTIFY	ASSET MANAGEMENT	X	X	X	X
	BUSINESS ENVIRONMENT	X	X	X	X
	GOVERNANCE	X			
	RISK ASSESSMENT	X	X	X	X
	SUPPLY CHAIN RISK MANAGEMENT	X		X	X
PROTECT	ACCESS CONTROL	X	X	X	X
	AWARENESS AND TRAINING	X			
	DATA SECURITY	X	X	X	X
	INFORMATION PROTECTION PROCESSES AND PROCEDURES	X	X		X
	MAINTENANCE	X	X	X	X
	PROTECTIVE TECHNOLOGY		X	X	X

		Identify systems dependent on PNT services	Identify appropriate PNT sources	Detect disturbance and manipulation of PNT services	Manage the risk to PNT systems
DETECT	ANOMALIES AND EVENTS	X		X	X
	SECURITY CONTINUOUS MONITORING	X	X	X	X
	DETECTION PROCESS	X		X	X
RESPOND	RESPONSE PLANNING				X
	COMMUNICATIONS	X			X
	ANALYSIS			X	X
	MITIGATION			X	X
	IMPROVEMENTS				X
RECOVER	RECOVERY PLANNING	X		X	X
	IMPROVEMENTS	X		X	X
	COMMUNICATIONS	X		X	X

The Executive Order defines four components, and the CSF defines a set of Functions and Categories. The PNT Profile maps the components of the Executive Order to the CSF. It is important to note that there are interdependencies between the CSF Functions and that each component of the Executive Order will require multiple Functions, Categories, and Subcategories.

Successful implementations require a comprehensive approach. The CSF Functions and guidance in the PNT Profile address the generic needs of PNT users in critical infrastructure that depend on PNT services to meet their business objectives. In order to support a risk-based, practical, and effective approach to the responsible use of PNT, organizations can select, tailor, and augment the security controls defined in PNT references in Sections 4.1 through 4.5.

4.1 Identify Function

The Identify Function is foundational to the risk assessment process. It is highly recommended that those who intend to implement all or part of the PNT Profile start with the Identify Function. An organization needs to analyze its mission objectives related to its reliance on PNT data.

The Identify Function provides key activities that should be given strong consideration in this analysis. Consideration of the organization's mission and business objectives, threat environment, assets, and vulnerabilities will have a significant influence on the overall risk; these are directly addressed in the other four CSF Functions (i.e., Protect, Detect, Respond, Recover).

The objectives of the Identify Function include:

- Identify the business or operational environment and organization's purpose;
- Identify all assets, including applications dependent on PNT data;
- Identify sources and infrastructure that provide PNT information; and
- Identify the vulnerabilities, threats, and impacts should the threat be realized in order to assess the risk.

The Identify Function within the Cybersecurity Framework defines six Categories, five of which have at least one Subcategory that applies to the PNT Profile to varying degrees, as summarized in Sections 4.1.1 through 4.1.5.

4.1.1 Asset Management Category

The data, personnel, devices, systems, and facilities that enable the organization to achieve its business objectives are identified and managed in a manner that is consistent with their importance to organizational objectives and the organization's risk strategy. In the context of the PNT Profile, the assets that require and support PNT services in order to fulfill the organization's mission and business objectives are identified.

There are five Subcategories within Asset Management that apply to the PNT Profile, as summarized in the table below.

Table 3 - Identify – Asset Management Subcategories Applicable to PNT

Identify **Asset Management** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
AM-1: **Physical devices and systems within the organization are inventoried.**	Document and maintain an inventory of the PNT system components that reflect the current system. The physical inventory should include PNT system components used to support critical infrastructure/operations and critical system components that rely on PNT data and services to properly function. PNT system components may include GNSS receivers, wireless local area network (WLAN) receivers, terrestrial beacon system receivers (TBS), radio navigation or timing antennas, network switches, Internet of Things (IoT)/ Supervisory Control and Data Acquisition (SCADA) devices, NTP and Precision Time Protocol (PTP) servers, positioning sensors, clocks, etc. Cryptographic modules, test and measurement equipment, navigation systems, etc. are examples of hardware and devices dependent on PNT services. Incorporate a configuration management tool that documents locations of all PNT antennas and verify with physical inspections. During physical inspections, identify equipment associated with PNT devices and locate PNT service provider interfaces, such as GNSS antennas.	**3GPP TS 36.305** 4.3 **DHS CISA** 1.a, 2.a **ICAO 9849** 1.4 **IEEE 1588** 6, 9, 10 **IEEE 802.1AS** 7, 11 **IEEE 2030.101** 4.6, 4.7, 4.8, 4.9 **NIST SP 800-53 Rev. 5** CM-8, CM-9 PM-5 **NIST SP 800-160 Rev. 1** 2.3 **RTCA 229** 2.1.5.2.1, 2.4, 2.5 **RTCA 292** 2.5 **RTCA 326** 3.1 **USG FRP** 1.7.8, 4.4.2, 4.6, 5.1.2, 6

Identify Asset Management Subcategory	Applicability to PNT	References (PNT-Specific)
AM-2: **Software platforms and applications within the organization are inventoried.**	The software inventory should include PNT system components used to support critical infrastructure/operations and critical applications that rely on PNT data and services to properly function. Document and maintain an inventory of PNT system software components, such as software license information, software version numbers, human-machine interface (HMI), and other industrial control systems (ICS) component applications, software, and operating systems. System software inventory is reviewed and updated as defined by the organization. Identify all software, applications, and systems that are dependent on PNT data, including software that relies on distributed time, using phase and frequency synchronization methods. These methods may include packet-based communication protocols (e.g., NTP, PTP), frequency protocols using the physical layer network (e.g., Synchronous Ethernet (SyncE)), or physical signals (e.g., 10 MHz, 1 PPS, Inter-range instrumentation group time code B (IRIG-B)). Applications dependent on PNT data may include test and measurement tools, kernels, databases, logging software, cryptography/certificate management, and other software that rely on synchronized clocks or positioning information to verify information consistency. Some functions, such as	**3GPP TS 36.305** 4.3 **DHS CISA** 1.a, 1.b, 1.c, 2.a **DHS PNT** Appendix C **ICAO 9849** 1.4, 5.1.4 **IEEE 1588** 5-14, Annex A, P **IEEE 802.1AS** 7, 10 **IEEE 2030.101** 4.3 **IETF 5905** 5-15 **IETF 7384** 5, 7 **IMO 1575** Appendix C **ITU-T G.8261** 6, 7, Annex A **NIST SP 800-53 Rev. 5** CM-8, PM-5 **RTCA 229** 2.1.5.2.1, 2.2.1.2, 2.2.1.3, 2.2.1.4, 2.2.1.5 **RTCA 292** 2.4

Identify **Asset Management** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	multilateration, are also sensitive to timing performance, and should therefore be inventoried.	**RTCA 326** 3.1
AM-3: **Organizational communication and data flows are mapped.**	Identify all connections within the PNT system, as well as between the PNT system and other systems. All connections and signal interfaces are documented, authorized, and reviewed. Connection information may include the physical interface characteristics, logical interface characteristics, data characteristics, ports, port configurations, protocols, addresses, description of the data, security requirements, and nature of the connection. Identify the PNT data source and distribution medium for the applications and systems that meets the PNT data performance and resilience requirements needed. It is critical to know where each system derives PNT data from. For example, the organization may want to investigate software programs that can help its organization identify PNT data sources to assess which sources are most beneficial to organizational mission stability. For each software that provisions or uses PNT data, identify the input and output data interfaces.	**DHS CISA** 1, 2 **GPS IS-200** 3 **GPS IS-705** 3 **GPS IS-800** 3 **GPS SPS** B.1.2, B.1.3 **IEC 61850-90-4** 10, 14 **IEEE 1588** 8-12 **IEEE 802.1AS** 7.4, 8.5 **IEEE 2030.101** 4.2 **IETF 5905** 5-14 **IMO 1575** A-D, Appendix C **ITU-T G.8261** 6 **ITU-T G.8262** 6-12, Appendix III

Identify **Asset Management** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
		ITU-T G.8272 6-12 **NIST SP 800-53 Rev. 5** AC-4, CA-3, CA-9, PL-8, SA-17 **RTCA 326** 3.1.1
AM-4: **External information systems are catalogued**.	Identify and catalogue all external connections for the PNT system. Identify all PNT signals, data sources, and related data products that pertain to an event or the status of the PNT source. Examples of external systems include engineering design services and those that are controlled under separate authority, personal devices, and other hosted services.	**DHS CISA** 3 **NIST SP 800-53 Rev. 5** AC-20, PM-5, SA-9 **USG FRP** Appendix B
AM-5: **Resources (e.g., hardware, devices, data, time, personnel, and software) are prioritized based on their classification, criticality, and business value.**	Determine required resources to support current regulations and standards requirements for the responsible use of PNT systems. Provide adequate staffing with the appropriate training such that PNT support is available in a timely manner (consistent with thresholds defined in the organization's business plan). Formalize PNT roles and responsibilities to provide a process for transitioning staff members (with PNT expertise) to be	**DHS CISA** 3 **NIST SP 800-37** 3 **NIST SP 800-53 Rev. 5** AC-20, RA-9 **USG FRP** Appendix B

Identify Asset Management Subcategory	Applicability to PNT	References (PNT-Specific)
	replaced. The remaining staff members are provided with necessary resources and PNT training. Identify and prioritize PNT system components, processors, and functions based on their classification, criticality, and business value. Identify the types of information in the organization's possession, custody, or control for which security safeguards are needed (e.g., sensitive or protected information). Stakeholders are advised to use other functions within the CSF to inform identification procedures. For example, while testing business continuity procedures, use the findings of a lost PNT source to identify which aspects of the mission were impacted and to what degree, and reprioritize accordingly. When identifying resources and prioritizing trade-offs for PNT systems, holistically consider requirements, such as availability, continuity, data integrity, timeliness of anomaly detection, response, and recovery.	

4.1.2 Business Environment Category

The organization's mission, objectives, stakeholders, and activities are understood and prioritized. This information is used to inform cybersecurity roles, responsibilities, and risk management decisions. In the context of this PNT Profile, identify activities that are facilitated or require PNT services in order to fulfill the organization's mission, objectives, or other stakeholders' needs.

There are two Subcategories within Business Environment that apply to the PNT Profile, as summarized in the table below.

Table 4 - Business Environment Subcategories Applicable to PNT

Identify **Business Environment** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
BE-4: **Dependencies and critical functions for the delivery of critical services are established.**	Identify and prioritize internal critical business services that are dependent on PNT system processes and components. Identify any consumers and their requirements that rely on the organization's products or services whose delivery or production is derived from or relies upon PNT data. Recognize that different users and applications may have different requirements. Identify and prioritize supporting services for critical PNT system processes and components. For organizations that form PNT data, understand PNT data performance, the resilience levels of the service provided, and customer dependencies on PNT data. The organization's infrastructure, such as network communication architectures and protocols, can impact recovery time in the event of a path or node failure.	**DHS CISA** 3.a, 3.b, 3.c **GPS** 2, 3, 4, 5 **GPS SPS** 3 **IEEE 2030.101** 4.4-4.7 **NIST SP 800-53 Rev. 5** CP-8, PE-9, PE-11, PM-8, RA-9 **USG FRP** 4, 6

Identify **Business Environment** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
BE-5: **Resilience requirements to support the delivery of critical services are established for all operating states (e.g. under duress or attack, during recovery, normal operations.)**	Consider and prioritize requirements in the context of safety, operational criticality, cost, and other resource availability. Identify performance levels of PNT data regardless of environmental threats or if applications can rely on alternatives without the PNT data (systems/components). Identify PNT data traceability requirements and reconcile with the PNT data performance (e.g., accuracy, integrity, continuity, availability, coverage) for the software, applications, systems, and environment in which the system is operating. Where applicable and practical, identify network performance parameters at the device's ingress and egress ports, static and dynamic delays between nodes, and end-to-end delay characteristics for the distribution of PNT data. Resiliency requirements permit an organization to determine if the full capability of its current PNT service provider is needed. For example, if relative time synchronization or frequency synchronization is sufficient, then an organization may have more complementary holdover reference options. PNT applications that require only a relative frame of reference may have additional resilience capabilities using local sensors, signals of opportunity, computations, and communications.	**3GPP TS 22.878** 4, 5 **DHS CISA** 6 **DHS PNT** III-V **DHS RCF** 5-7 **GPS SPS** 3 **IEC 61850-90-4** 14.2.4 **IEEE 1588** 12.2 **IETF 8633** 3.2, 3.3 **ITU-T G.8262** 11 **ITU-T G.8272** 7 **ITU-T G.8275.1** Appendices I, II **NIST SP 800-53 Rev. 5** CP-2, CP-11, RA-9, SA-8 **RTCA 229** 2.1.1.4, 2.1.2.3- 2.1.2.6, 2.1.3.3-2.1.3.6, 2.1.4.3- 2.1.4.7, 2.1.5.3 -2.1.5.7, 2.2.1.1, 2.2.1.2-2.2.1.6 **RTCA 235** 14.2, 14.3, 14.4 **USG FRP 1.7, 6**

4.1.3 Governance Category

The policies, procedures, and processes to manage and monitor the organization's regulatory, legal, risk, environmental, and operational requirements are understood and inform the management of cybersecurity risk. In the context of this PNT Profile, identify the legal, risk, environmental, and operational requirements that are enabled or impacted using PNT services.

There is one Subcategory within Governance that applies to the PNT Profile.

Table 5 - Governance Subcategory Applicable to PNT

Identify **Governance**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
GV-4: **Governance and risk management processes address cybersecurity risks.**	Develop a comprehensive strategy to manage risk to PNT-dependent operations. Include cybersecurity considerations in the risk management strategy. Review and update the risk management strategy, as necessary. Understand governance structure, including quality assurance and oversight, of PNT sources, applications, and systems using PNT data for critical applications with respect to traceability, performance monitoring, and resilience requirements. Implementations that include complementary or redundant PNT sources need to consider governance and risk implications, such as the interoperability, compatibility, and interchangeability of different sources. Verify that any impacts to the PNT data output are not detrimental to the mission. For example, understand how multiple GNSS	**DHS CISA** 2.b, 2.c, 3.a **DOT CMPS** **FINRA 4590** **GPS GNSS** **GPS IS-200** 3.3.4, 20.3.3.4.3.3.1 **ICAO 9849** 1, 6.2, 6.3, 7.2, 7.3, 7.15, 7.16 **IEEE 2030.101** Annex C **Matsakis 2018**

Identify Governance Subcategory	Applicability to PNT	References (PNT-Specific)
	constellations with different geodetic reference frames and time scales impact the PNT data output. GPS uses the WGS-84 geodetic reference frame for positioning and the GPS time scale is synchronized to UTC(USNO) within 1 µs. Foreign PNT service providers, such as satellite constellations, should only be used in accordance with current federal policy guidance and restrictions. Be aware of legally accepted standards and sources. For example, UTC(NIST) and UTC(USNO) are the sources of legal time in the U.S. Understand standards that support interoperability for PNT services and national/international coordination to support the performance, standardization, and cost minimization of user equipment. Consider the governance and risk implications of using multi-GNSS receivers as well as practical considerations, such as interoperability and interchangeability of the different GNSS constellations for the organization's applications.	**NIST SP 800-53 Rev. 5**, PM-3, PM-7, PM9, PM-10, PM-11, PM-28, RA-1, RA-2, RA-3, SA-2 **NIST SP 800-160 Rev. 1** 3.3.8 **RTCA 229** 1.3.3 **RTCA 326** 3.1.2 **USG FRP** 1.7.5 through 1.7.9, 6 **USNG** **VIM**

4.1.4 Risk Assessment Category

The organization understands the cybersecurity risk to operations (including mission, functions, image, or reputation), assets, and individuals. In the context of this PNT Profile, the risk to organizational operations in the event of disruption or manipulation to PNT services is the main concern.

There are five Subcategories within Risk Assessment that apply to the PNT Profile, as summarized in the table below.

Table 6 - Risk Assessment Subcategories Applicable to PNT

Identify **Risk Assessment** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
RA-1: **Asset vulnerabilities are identified and documented.**	Identify, document, and report vulnerabilities that exist on the PNT system and the system that distributes PNT data. Where safe and feasible, include the use of vulnerability scanning on the PNT system, its components, or a representative system. Testing and characterization to assess system vulnerabilities are recommended periodically or when there are changes to the threat model, the organization's reliance on PNT data, or modifications to the PNT equipment. Receiver or system vulnerability testing may include PNT signal simulation to assess susceptibility to disruption or manipulation of the PNT signal. Testing should be conducted in accordance with industry best practices, laws, and regulations as well as within the business continuity constraints defined for the organization. Vulnerabilities for an operational environment may include the susceptibility to atmospheric and scintillation effects on PNT signals, spoofing of unauthenticated signals, or disruptions or manipulations of PNT services.	**DHS CISA** 4.a **DHS GPS CI** **ICAO 9849** 5, 7.13 **IEEE 2030.101** 4.12, 4.14, 5 **NIST SP 800-53 Rev. 5** CA-2, CA-7, CA-8, PM-15, RA-3, RA-5, SA-5, SA-11, SI-2, SI-4, SI-5 **NTP SEC** **RTCA 229** 1.6.2, 2, 2.1.1.1.4, 2.1.1.1.5, 2.4, 2.5 **RTCA 356** 3.8.1, 3.8.2 **Teasley 1995** **Volpe 2001** 3-7 **USG FRP** 1.7.3
RA-2:	Establish and maintain ongoing contact with security groups and associations to receive security alerts and advisories.	**DOT CGSIC**

Identify **Risk Assessment** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
Cyber threat intelligence is received from information-sharing forums and sources.	Security groups and associations may include special interest groups, forums, professional associations, news groups, and peer groups of security professionals in similar organizations. Implement a collaborative threat research and awareness program that includes a cross-organization information-sharing capability. Organizations should consider having both unclassified and classified information-sharing capabilities. The coordination of information is important in building a comprehensive threat assessment indicator of evolving threats in the operating environment, including the geographical and temporal characteristics of the threat.	**DHS CISA** 4.a **ICS-CERT** **NCCIC** **NERC EISAC** **NTP SEC** **NIST SP 800-53 Rev. 5** PM-15, PM-16 **USG FRP** Appendix B
RA-3: **Threats, both internal and external, are identified and documented.**	Threats in an operational environment may include natural, manufactured, intentional, and unintentional disruptions and manipulations, such as radio frequency interference (RFI), denial of service, data manipulation, unpredictable or uncharacteristic delays in the communication of PNT data, or loss of PNT service. The threat assessment should include internal and external parties, user errors, hardware or software errors, compromise, failure, network impairments, and environmental conditions. Examples of threats to PNT data availability and integrity include (i) PNT user or component	**DIA** **DOT 12464** **DOT CGSIC** **DHS GPS CI** **GPS SPS** A.5.4.1 **ICAO 9849** 5.3- 5.5, Appendix F **IETF 7384** 3 **IETF CMP** 6

Identify Risk Assessment Subcategory	Applicability to PNT	References (PNT-Specific)
	errors or impaired PNT components and communications; (ii) RFI, such as signal blockage, multipath, atmospheric scintillations, and interference from other radio frequency sources; (iii) other environmental threats, such as temperature variations, aging, vibrations, and power outages; (iv) hostile attacks, such as jamming, spoofing, High-Altitude Nuclear Detonation, High-Altitude Electromagnetic Pulse, or PNT component or network compromises (e.g., denial of service and delay attacks); and confidentiality, especially when PNT data is bound or associated with sensitive data.	**ITU-T 810** 6 **ITU-T GNSS** Appendix II, V, VII **Kaplan** 9, 10 **NASIC** **NIST CSF** Appendix A ID.RA-P1-ID.RA-P3 **NIST SP 800-37** 2 **NIST SP 800-53 Rev. 5** PM-12, PM16, RA-3, SI-5 **NIST SP 800-160 Rev. 1** 2.3 **RTCA 235** 4-12 **RTCA 292** 2-14 **RTCA 326** 3.2 **RTCA 356** 3.2, 3.3, 3.4, 3.5
RA-4: **Potential business impacts and likelihoods are identified.**	The likelihood of an attack is a function of the capability and intent of a potential adversary that may be influenced by non-technical factors. For example, a foreign GNSS provider may deny PNT to the U.S. in a time of war or heightened tensions. Foreign satellite constellations should only be used in accordance with current federal policy guidance and restrictions.	**DOT 12464** **NIST SP 1065** 3-12 **NIST SP 800-53 Rev. 5** CP-2, PM9, PM-11, PM-9, RA-2, RA-3, RA-9 **NIST TN 1366** **RTCA 235** 2.1,13

Identify Risk Assessment Subcategory	Applicability to PNT	References (PNT-Specific)
	Identify the potential business impacts of the disruption or manipulation of PNT service. The impact of a realized threat on PNT data performance and resilience may be evaluated in a test or field environment. Consider the impact of both observed and anticipated threats on downstream applications and users, as well as the potential interval of time during which the threat can continue. For each identified threat, include the extent of impact, error manifestation (step or ramp error and rate of ramp), detection thresholds, and error propagation implications on safety and operations. Understand that the vulnerabilities for a system or component may impact dependent systems (i.e., a vulnerability may have impacts beyond the system that was subjected to an exploit). Based on applications' PNT data performance requirements, identify, characterize, and document the error sources of PNT data where applicable. Documenting PNT measurement uncertainty characteristics in conjunction with the assessed vulnerability exploits is useful in order to assess whether the PNT data meets mission requirements. For example, time signals and data are subject to phase variations due to frequency drift, frequency offset, jitter, wander, and discontinuities. Phase discontinuities can be caused by changes in the time source or in the network topology, where errors in signal	**RTCA 292** 2.3-2.6

Identify Risk Assessment Subcategory	Applicability to PNT	References (PNT-Specific)
	regeneration or analog to digital conversion can contribute to performance degradation.	
RA-5: **Threats, vulnerabilities, likelihoods, and impacts are used to assess risk.**	Conduct and document periodic assessments of risk to PNT systems that consider the threats, vulnerabilities, the likelihood that the threat will be realized, and the impact (including scale) to operations and assets. The residual risk should be reassessed on a periodic basis, when there is a substantive change to the system's vulnerabilities (such as an equipment upgrade), a change in the likelihood of threat realization (such as a time of international tension), a change in the impact should a threat be realized (such as an organization's increased use or dependency on PNT services), or as a result of lessons learned from recovery actions. The organization's failure and fault analysis should include all known threats to business processes due to a loss of PNT data assurance for a given operational environment. Estimate the internal, external, environmental, intentional, and unintentional risks to the business or mission based the impact of a PNT disruption or manipulation. Consider the feasibility of continued operations.	**DHS GPS CI** **ICAO 9849** 7.4, 7.5, Appendix F **IETF 7384** 3.1-3.3 **IETF 8633** 3-9 **IETF 8915** 3-9 **IETF CMP** **NIST CSF** ID.RA-P4, ID.RA-P5, Appendix D **NIST SP 800-53 Rev. 5** CA-2, CA-7, PM-16, PM-28, RA-2 **NIST SP 800-160 Rev. 1** 2.3, 2.4 **RTCA 235** 2.1-2.4, 3, 14 **RTCA 326** 2.1, 2.2, 3.1- 3.4 **RTCA 356** 2.7, 3.5

4.1.5 Supply Chain Risk Management Category

The organization's priorities, constraints, risk tolerances, and assumptions are established and used to support risk decisions associated with managing supply chain risk. The organization has established and implemented the processes to identify, assess, and manage supply chain risks. In the context of this PNT Profile, identify the PNT service providers in order to assess and manage the risk to the PNT service.

There is one Subcategory within Supply Chain Risk Management that applies to this PNT Profile, as summarized in the table below.

Table 7 - Supply Chain Risk Assessment Subcategory Applicable to PNT

Identify **Supply Chain Risk Management**		
Subcategory	**Applicability to PNT**	**References (PNT Specific)**
SC-2: **Suppliers and third-party partners of information systems, components, and services are identified, prioritized, and assessed using a cyber supply chain risk assessment process.**	Identify any external systems or services that the organization uses for ingesting PNT data. Remain apprised of current and future regulations related to the acquisition of PNT services, sources, and devices forming, transporting, or using PNT data. Identify any external systems or services that the organization is dependent on for its PNT data. In making supply chain decisions on PNT systems, components, and services, considerations may include (i) functional requirements; (ii) any relevant and applicable federal law, regulation, or statutory policy; (iii) the threat environment; (iv) mission-level goals, criticality, and functions; (v) security policies; (vi) organizational policies,	**DHS GPS CI** 5 **NDAA** 889 **NIST SP 800-161** 2.2, 3 **NIST SP 800-53 Rev. 5** PM-9, RA-3, SR-2, SR-3, SR-5, SR-6 **USG FRP** 1.7

Identify Supply Chain Risk Management Subcategory	Applicability to PNT	References (PNT Specific)
	vulnerabilities, risks, and risk tolerance; and (vii) the business objectives. Supply chain vulnerabilities include (i) systems and components; (ii) the development and operational environment; and (iii) the logistics or delivery environment that transports systems and components (logically or physically). Consider access paths within the supply chain that would allow adversaries to gain information about the PNT system and introduce hardware, software, or firmware that could cause the disruption or manipulation of the PNT data as well as any dependencies that may be easier to subvert. Supply chain threat sources include (i) hostile cyber or physical attacks to either the supply chain or an information system component traversing the supply chain; (ii) human errors; and (iii) geopolitical disruptions, economic upheavals, and natural or manufactured disasters. Likelihood determination of PNT supply chain exploits include (i) threat information and assumptions; (ii) PNT component exposure to external access; (iii) system, process, or component vulnerabilities; and (iv) empirical data on vulnerabilities from system, process, and component test and analysis results.	

Identify Supply Chain Risk Management Subcategory	Applicability to PNT	References (PNT Specific)
	Mission criticality and impact analysis of supply chain vulnerabilities, threats, and likelihood of PNT systems and components can be used to determine the organization's risk and guide the selection of supply chain security controls.	

4.2 Protect Function

The Protect Function includes development, implementation, and verification measures to prevent the loss of functionality in the case of PNT disruption or manipulation. Additionally, the Protect Function enables the response to and recovery from cybersecurity events with planning and preparation activities, while the execution of risk mitigation is addressed in the Response and Recovery Functions.

The objectives of the Protect Function include:

- Protect the systems that form, transmit, and use PNT data to support the needed level of integrity, availability, and confidentiality based on application needs.
- Protect the deployment and use of PNT services through adherence to cybersecurity principles, including understanding the baseline characteristics and application tolerances of the PNT sources, data, and any contextual information; providing sufficient resources; managing the systems development life cycle (SDLC); and deploying needed training, authorizations, and access control.
- Should a threat be realized, protect users and applications that are dependent on PNT data by enabling them to maintain a sufficient level of operations through verified response and recovery plans.
- Protect organizations that rely on PNT services and data with respect to business and operational needs.

The Protect Function defines six Categories, all of which have at least one Subcategory that applies to this PNT Profile to varying degrees, as summarized in Sections 4.2.1 through 4.2.6.

4.2.1 Access Control Category

Access to physical and logical assets and associated facilities is limited to authorized users, processes, and devices and is managed consistent with the assessed risk of unauthorized access to authorized activities. In the context of this PNT Profile, assets may include GNSS antennas, receivers, servers, and subscriptions, and "physical access" may include radio frequency emanations.

There are seven Subcategories within Access Control that apply to this PNT Profile, as summarized in the table below.

Table 8 - Protect Access Control Categories Applicable to PNT

Protect **Access Control** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
AC-1: **Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes.**	Where applicable, establish and manage identification and authentication credentials of PNT users, data sources, and applications that use PNT data. When warranted, authenticate PNT sources and data to verify PNT data integrity. Authentication can also be used to verify that PNT resources are used by authorized devices, users, and processes. Revoke credentials when the authorization of PNT sources, devices, users, and processes expires or is no longer needed.	**DHS GPS CI** **DHS TFS** 3.10, 3.11 **IEEE 1588** Annex P 2.1.2 **IETF 5906** 7, 8, 10 **IETF 7384** 5.1 **IETF 8915** 1, 5.2, 5.6, 5.7, 8 **NIST SP 800-53 Rev. 5** IA-1, IA-2, IA-3, IA-4, IA-5, IA-7, IA-8, IA-10, IA-11, IA-12
AC-2:	Protect physical access to the PNT equipment and resources. Determine access requirements during emergency situations.	**DHS GPS CI**

Protect **Access Control**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
Physical access to assets is managed and protected.	Maintain and review visitor access records to the facility where the PNT equipment resides, including antennas. The access and provisioning process may include lists of authorized individuals, identity credentials, escort requirements, guards, fences, turnstiles, locks, and the monitoring of facility access. For example, obscure the visibility of antennas from public access, or use decoy antennas.	**NIST SP 800-53 Rev. 5** PE-1, PE-2, PE-3, PE-4, PE-5, PE-6, PE-8, PE-9
AC-3: **Remote access is managed.**	Establish usage restrictions, connection requirements, implementation guidance, and authorizations for remote access to the systems that use or form PNT data. Consider radio frequency as part of remote access and employ appropriate mitigations at the receiving antennae. Enable secure remote access and management to PNT systems and devices. Compliance to secure standardized network management protocols can facilitate remote network management and monitoring. Ensure the safe use of service and management protocols by following security alerts and adhering to latest best practices. Document the use of security capabilities, such as access control lists, authentication, and configuration parameters to reduce the probability of cyberattacks.	**DHS GPS CI** **DHS TFS** 3.11 **IETF CMP** 1, 4, 6 **IEEE 1588** Annex P 2.5.3 **IETF CMP** 3-6 **NIST SP 800-53 Rev. 5** AC-1, AC-17, AC-19, AC-20, SC-15 **SNMP3** **SNMPSEC**

Protect **Access Control**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
AC-4: **Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties.**	Create access control lists that enforce which authenticated users are authorized to use or perform actions on PNT systems. Enable approved access lists for all controls that follow, such as NTP and PTP time servers, signaling channels, and other PNT systems. Define and manage access permissions for systems that use PNT services. Identify user actions that can be performed on the systems that use or form PNT data without needing to verify identification or authentication (e.g., during emergencies).	**IEEE 1588** Annex P 2.1.2, 2.5.2, 2.5.5 **IETF 8633** 3.4, 5.1 **NIST SP 800-53 Rev. 5** AC-1, AC-2, AC-3, AC5, AC-6, AC-14, AC-16, AC-24 **NIST SP 800-160 Rev. 1** Appendix F.1.14
AC-5: **Network integrity is protected (e.g., network segregation, network segmentation).**	Identify and control connections between system components. Monitor and control connections and communications at the external boundary and at key internal boundaries. Information Assurance (IA) measures to ensure integrity should be considered at the network boundaries and internal controls. Boundary protection mechanisms may include boundary clocks, routers, gateways, unidirectional gateways, data diodes, and separating system components into logically separate networks or subnetworks. Intradomain measures include network segmentation and segregation where appropriate. Consider the isolation of control plane, user plane, and signaling plane where appropriate and practical.	**DHS CISA** 1.a, 4.a **IEEE 1588** Annex P **IETF 5906** 6 **IETF 7384** 5.2 **NIST SP 800-53 Rev. 5** AC-4, SC-7, SC-10

Protect **Access Control** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
AC-6: **Identities are proofed and bound to credentials and asserted in interactions.**	Prior to issuing identity credentials and authorizations to form or to use PNT data, determine the identity and any associated contextual information needed about a user, device, or process to establish a satisfactory level of assurance. Contextual information used to proof user or asset identity may include proximity, location, movement, associations, and environmental factors. PNT data sources are validated for authenticity. Clients, applications, and systems are validated for the authorized use of the PNT data or services. Note that the sensitivity (and associated confidentiality requirements) of PNT data may be impacted when bound or associated with other data.	**ATIS-I-0000070** 2-7 **DHS CISA 2.d** **DHS GPS CI** **IEEE 1588** 16.14, Annex P **IETF 5906** 7, 8-10 **NISTIR 8014** 4-6 **NIST SP 800-53 Rev. 5** AC-1, AC-2, AC-3, AC16, AC-19, AC-24, IA-1, IA-2, IA-4, IA-5, IA-8, IA-12, PE-2, PS-3
AC-7: **Users, devices, and other assets are authenticated (e.g., single-factor, multi-factor) commensurate with the risk of the transaction (e.g., individuals' security and privacy risks and other organizational risks).**	Ensure that PNT devices and equipment use appropriate authentication for the risk associated with downstream operations, which depend on accurate and reliable PNT data. Not all PNT services support authentication, and alternates should be sought when practical and warranted. Users, devices, and assets are authenticated to prevent the realization of cyberthreats via remote connections to the PNT data source. Authentication protects data provenance and verifies the authenticity of the data source. Implement source, client,	**DHS CISA** 2.d, 5.b **DHS GPS CI** **DHS TFS** 2.2 **IEEE 1588** 16.14, Appendix P.2.1, 2.2 **IETF 4082** 2-5 **IETF 5906** 2-12 **IETF 7384** 5.1, 5.7 **IETF 7822** 2-4

Protect Access Control Subcategory	Applicability to PNT	References (PNT-Specific)
	or mutual authentication based on the IA requirements of the organization and be cognizant of the fact that different applications may have different authentication requirements. Understand that implementations may influence message delay and delay variations. Verify that PNT data performance remains within tolerances.	**IETF 8573** 3-7 **IETF 8633** 5.5, 5.6 **IETF 8915** 1,4, 5.5, 8.3, 8.4 **NIST NTP** **NIST SP 800-53 Rev. 5** AC-14, IA-1, IA-2, IA-3, IA-5, IA-8, IA-9, IA-10, IA-11

4.2.2 Awareness and Training Category

The organization's personnel and partners are provided cybersecurity awareness education and trained to perform their cybersecurity-related duties and responsibilities consistent with related policies, procedures, and agreements. In the context of this PNT Profile, the focus is on privileged users who monitor and maintain equipment that forms, communicates, or uses PNT data.

There is one Subcategory within Awareness and Training that applies to the PNT Profile.

Table 9 - Awareness and Training Subcategory Applicable to PNT

Protect **Awareness and Training**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
AT-2: **Privileged users understand their roles and responsibilities.**	Determine how to establish what privileged user qualifications are, what training is required to meet those qualifications, and ways to validate that the qualifications have been met. Consider comprehensive training programs for transitioning staff assigned to the business and operational implementation of the organization's PNT services and applications that are dependent on PNT data. Operators, network and system administrators, and other technical staff are trained to install, test, and maintain PNT systems, as well as to detect and respond to compromised PNT data with respect to the PNT data source and applications or systems that use PNT data.	**DHS CISA** 5.a **ICAO 9849** 1.3.1, 1.3.4, 7.3, 7.4, 7.5.6, 7.6.1 **NIST SP 800-53 Rev. 5** AT-3, PM-13 **NIST SP 800-160** Appendix E **USG FRP** 1.7.8

4.2.3 Data Security Category

Information and data are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of PNT services. In this PNT Profile, the availability and integrity of PNT services are of primary concern throughout the enterprise. PNT data that is bound or associated with personally identifiable information (PII) or other sensitive data increases the confidentiality concerns.

There are seven Subcategories within Data Security that apply to the PNT Profile, as summarized in the table below.

Table 10 - Data Security Subcategories Applicable to PNT

Protect **Data Security** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
DS-1: **Data at rest is protected.**	Applications dependent on PNT data, such as location and time stamp to log the position and time of an event, may need to protect against repudiation and alteration. Sensitive information may need to be encrypted. PNT data may be critical for downstream activities, such as analytics and forensics. Apply measures such as access control lists, encryption, and other data-at-rest protections commensurate with the criticality of the activities dependent on PNT.	**GPS ICD-870** 3.3, 3.3.1 **IETF CMP** 6 **NIST CSF** Appendix A CT.DP-P1-CT.DP-P4 **NIST SP 800-37** 3 **NIST SP 800-53 Rev. 5** MP-3, MP-4, MP-6, SC-28
DS-2: **Data in transit is protected.**	Use encryption and transmission security in accordance with availability, integrity, and confidentiality requirements. Time protocols may need integrity, authentication, and—for certain use cases—confidentiality protections. Prior to deploying encryption or decryption implementations, understand the implementation's effects on PNT data communications delay and delay variances. Verify that the synchronization precision remains within the specified tolerances.	**IEEE 1588** 16.14, Annex P.2.2.1.3, P.2.2.3 **IETF 7384** 5.1-5.3, 5.7-5.9 **IETF 8915** 1, 3-9 **IETF NTS** 1-10 **NIST SP 800-53 Rev. 5** SC-8, SC-11, SC-12
DS-3: **Assets are formally managed throughout removal, transfers, and disposition.**	Depending on the assessment of the sensitivity of PNT data, enforce accountability for all PNT system components throughout the system life cycle, including removal, transfers, and disposition. Some of the asset management requirements can be met by implementing solutions that provide the hardware	**DHS CISA** 4.b **NIST SP 800-53 Rev. 5** CM-8, MP-6, PE-16, PE-20

Protect Data Security Subcategory	Applicability to PNT	References (PNT-Specific)
	inventory, software inventory, systems development life cycle management, and media sanitization technical capabilities.	
DS-4: **Adequate capacity to ensure availability is maintained.**	Provide enough capacity to meet PNT data performance requirements—including availability, stability, and timeliness—and verify that the capacity will perform within predefined thresholds under normal operating conditions as well as in the presence of PNT service disruptions and manipulation. Consider performing developmental and operational tests to verify and validate PNT service performance under normal and contested conditions. Consider the principle of defense in depth using independent, diverse, and isolated PNT sources and communication paths. For example, multi-GNSS and multi-frequency receivers may mitigate interference events and spoofing attacks, as well as avoid errors due to variations in ionospheric delays. However, foreign satellite constellations should only be used in accordance with current federal policy guidance and restrictions. Keep apprised of potential and scheduled disruptions from PNT service providers. Where needed, incorporate measures such as stand-alone and holdover capabilities or other means for deriving PNT data when PNT sources are unavailable.	**3GPP TR22.878** 4, 5 **3GPP TS36.305** 4.3 **DHS RCF** 3, 5.3, 5.4 **DHS PNT** IV, V **GPS GNSS** **ICAO 9849** 2.2.3, 2.2.4, 5.1, 6.2, Appendix G **IEC 62439-3** 4, 5 **IEEE 1588** Appendix P.2.3 **IEEE 2030.101** 4.6, 4.8, 4.9, 4.12, 4.13 **IETF 7384** 5.4 **ITU-T G.8262** 11 **ITU-T G.8275** 7.2 **Kaplan** 1.8, 12, 13 **NIST SP 800-53 Rev. 5** AU-4, CP-2, PE-11, SC-5 **NIST SP 800-160** Appendix F.4

Protect **Data Security** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
		RTCA 229 1.5.2, 2.1.1.7- 2.1.1.9, 2.1.2.3- 2.1.2.6, 2.1.3.7- 2.1.3.9, 2.1.4.7- 2.1.4.9, 2.1.5.7- 2.1.5.9, 2.5.9.2 **RTCA 356** 3.5, 5.6.1 **USG FRP** 1.7.5.2, 6
DS-5: **Protections against data leaks are implemented.**	Protect the PNT system against data leaks. Special attention must be paid to PNT data which is bound to or used in conjunction with potentially sensitive data, such as PII. The physical location of critical assets needs to be protected against data leaks.	**IETF 8633** 5.1 **IETF 8915** 1, 9 **NIST SP 800-53 Rev. 5** AC-4, AC-5, AC-6, PE19, PS-3, PS-6, SC-7, SC-8, SC-13, SC-31, SI-4,
DS-6: **Integrity-checking mechanisms are used to verify software, firmware, and information integrity.**	Implement methods to ensure integrity in the event of PNT data discrepancies among PNT sources. Protections should also be put in place to verify that PNT input signals conform with service interface specifications and prevent internal data corruption. Information integrity may be checked or verified using redundant or independent PNT sources. Methods to evaluate PNT data integrity include algorithms that check the consistency of PNT output data and estimate the current magnitude and characteristics PNT data errors and uncertainty. For example, using multiple GNSS frequencies and multiple constellations can provide a means to cross-	**3GPP TS36.305** 4.3 **DHS CISA** 2.c **DHS GPS CI** 3 **DHS RCF** 5.2, 7, 8 **DHS ST** **GPS GNSS** **GPS IS-200** **GPS IS-705** **GPS IS-800** 3 **GPS ICD-240**

Protect Data Security Subcategory	Applicability to PNT	References (PNT-Specific)
	check PNT data and potentially remove error sources. However, foreign satellite constellations should only be used in accordance with current federal policy guidance and restrictions. Be aware of the potential for PNT data ambiguities in the PNT system and prepare users and applications to resolve any potential ambiguity (when two or more PNT systems disagree). Consider PNT systems that employ authentication and encryption of PNT data to preserve integrity and resist spoofing. Consider using an ensemble of multiple PNT sources to improve PNT data integrity and to estimate data uncertainties. Consider using PNT receivers that can verify that the data has been produced by a trusted identity and has not been modified. Consider PNT receivers that execute data integrity checks and IS/ICD/Data compliance checks to verify integrity and resist spoofing. Qualify new PNT firmware and software by verifying, validating, and executing documented device and end-to-end test plans under normal and failure mode conditions. Consider including potential PNT data interoperability issues	**GPS ICD-870** **ICAO 9849** 2.2.2, 4.1-4.4, 7.8, 7.10 **IEEE 1588** 16.14, Annex P 2.2 **IEEE 2030.101** 5 **IETF 5906** 4 **IETF 8633** 3.7, 4 **IETF 8915** 1, 5 **IMO 1575** Appendix C **NIST SP 800-53 Rev. 5** SI-7, SI-10 **NIST SP 800-160 Rev. 1** 2.3, 3.3.6, 3.4.9-3.4.11, Appendix F **RTCA 229** 1.6, 1.8.1.5, 2.1.1.1- 2.1.1.6, 2.1.1.10, 2.1.1.12, 2.1.2.1, 2.1.2.2, 2.1.3.1,2.1.3.2, 2.1.4.1, 2.1.4.2, 2.1.4.10, 2.1.4.11, 2.1.5.2, 2.2.1.6, 2.5.8, 2.5.9 **US FRP** 1.7, 4.3, A.1.10

Protect Data Security Subcategory	Applicability to PNT	References (PNT-Specific)
	in the affected application systems validation test plan, including leap second and GPS week rollover testing, well in advance of an event. For critical systems, consider verifying and validating PNT systems, components, and procedures through tests, measurements, inspections, and continuous monitoring.	
DS-8: **Integrity checking mechanisms are used to verify hardware integrity.**	Verify PNT device calibration, status, orientation (e.g., antenna positioning), and actual state compared to the desired state. Consider standards-based mechanisms, such as Trusted Platform Modules (TPM) and other device attestation measures when warranted and practical.	**DHS GPS CI** 4, 6 **IEEE 1588** Annex M, N **NISTIR 8250** 1-4, Appendix A **NISTIR 8320** **NIST SP 800-53 Rev. 5** PE-11, SA-10, SI-7

4.2.4 Information Protection Processes and Procedures Category

Security policies (that address purpose, scope, roles, responsibilities, management commitment, and coordination among organizational entities), processes, and procedures are maintained and used to manage the protection of information systems and assets. In the context

of this PNT Profile, the PNT data and services are subject to the security policies of the information that the PNT data is bound or associated with (e.g., PII, location of critical assets).

There are five Subcategories within Information Protection Processes and Procedures that apply to the PNT Profile, as summarized in the table below.

Table 11 - Information Protection Processes and Procedures Applicable to PNT

Protect **Information Protection Processes and Procedures**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
IP-1: **A baseline configuration of information technology / industrial control systems is created and maintained that incorporates security principles (e.g. concept of least functionality) is created and maintained.**	Document baseline information for PNT devices and components (e.g., serial numbers, license information, version numbers, HMI and other ICS component applications, patch information). Document configuration instructions and backups, architecture and wiring diagrams, and other PNT system information so that the reliance on and interdependency of PNT-related assets are understood and can be maintained. Install and configure PNT devices and components per manufacturer instructions using established safety and best practices guidelines. Understand the limitations of the original equipment manufacturer (OEM) equipment being fielded and consider the ability of the PNT devices and components to be suitable for the site's environment and adaptable to new features and protection mechanisms for PNT data. Periodically review and simplify PNT systems to reduce unknown interactions and effects. Configuring the PNT devices and components in a manner such that only	**3GPP TR22.878** 4, 5 **DHS CISA** 4.b, 5.b **DHS GPS CI** 11 **DHS TFS** 1, 2 **GPS-SPS** 2.4 **ICAO 9849** 6.4, Appendix F 5.2, 5.3 **IEEE 1588** Annex P **IEEE 2030.101** 4.6-4.13, 4.15 **IETF 5906** 5 **IETF 8633** 2-9 **IMO 1575** C.1, E **ITU G. 8272** I.1 **ITU-T G.8275** 7, 8 **ITU-T GNSS** 2, 4, 5, Appendix V, VII

Protect **Information Protection Processes and Procedures**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	essential capabilities are provided can reduce complexity and may reduce the attack surface. Network configuration and deployment can impact recovery time in the event of a path or node failure. Verify that the baseline configuration results in a system that meets the baseline PNT performance requirements, such as uncertainty, wander, and jitter tolerances.	**NIST SP 800-53 Rev. 5** CM-1, CM-2, CM-3, CM-4, CM5, CM-6, CM-7, CM-9, SA-10 **NIST SP 800-160** 3.4.9, 3.4.10, 3.4.11 Appendix F, G **NTP SEC** **RTCA 229** 2.2.1.1, 2.4.1, 2.5.2, 2.5.3, 2.5.4, 2.5.7, 2.5.11 **RTCA 235** 2.5.2.1, 2.5.2.2, Appendix G **RTCA 356** 3.5, 3.6, 5.6.1, 5.6.4, 5.6.5 **USG FRP** Appendix A
IP-2: **A System Development Life Cycle to manage systems is implemented.**	An operational system development life cycle for PNT services is established to incorporate and manage security measures throughout the life cycle of components. Document the requirements, approach, architectures, and assumptions used to minimize risks for systems that form or use PNT data, thereby verifying PNT data performance, such as the availability, integrity, and confidentiality of services. Consider the intended lifetime of the systems that form PNT data. The system components and architecture should be designed for complementary or redundant PNT sources to mitigate end-of-life and reliability issues, limit	**DHS CISA** 4.b **IEEE 2030.101** 4.5, 4.6 **NIST CSF** Appendix A CT.PO-P4 **NIST SP 800-53 Rev. 5** PL-8, SA-3, SA-4, SA-8, SA-10, SA-11, SA-15, SA-17, SI-12, SI-13, SI-14, SI-16, SI-17 **NIST SP 800-160 Rev. 1** 3.2.1, Appendix F.3 **RTCA 326** 4.2 **USG FRP** 1.4, 1.7.2

Protect Information Protection Processes and Procedures Subcategory	Applicability to PNT	References (PNT-Specific)
	the failure modes, and increase the probability that the organization's PNT systems are able to detect anomalous inputs and remain available through the presence of different threat models. Select, use, and ensemble complementary PNT services based on system priority classifications to meet business continuity objectives.	
IP-3: **Configuration change control processes are in place.**	Employ configuration change control for PNT devices and components that are consistent with the software development life cycle to maintain a functioning baseline and monitor all changes to validate impacts and integrity. Prior to deploying a change, conduct impact analyses. Identify and record the effects of impact on downstream applications, users, and downtime. Provide a mechanism so that changes in PNT firmware and software can be returned to a proper working state and should comply with the latest standards. Change control and maintenance procedures should include documentation and artifacts that will impact the performance of the PNT system, such as calibration procedures.	**DHS GPS CI** **IMO 1575** C.1, E.3 **NIST SP 800-53 Rev. 5** CM-3, CM-4, SA-10 **NIST SP 800-160 Rev. 1** 3.3.5 **RTCA 356** 3.8.3, 3.8.4
IP-9: **Response plans (Incident Response and Business**	Develop and maintain response and recovery plans that identify essential functions and associated contingency requirements, as well as provide a roadmap for implementing incident response. Plans should incorporate	**DHS CISA** 1.f **DHS IDM** **DHS RCF** 5-7

Protect **Information Protection Processes and Procedures**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
Continuity) and recovery plans (Incident Recovery and Disaster Recovery) are in place and managed.	recovery objectives, restoration priorities, tests, metrics, contingency roles, personnel assignments, and contact information. Prioritize maintaining essential functions despite system disruption or manipulation, as well as the eventual restoration of the PNT devices and components. As part of response planning, verify that systems have capabilities to mitigate PNT disruptions, such as anomaly detection with holdover capabilities. If complementary PNT sources are used, consider common failure modes and whether vulnerabilities of alternate and complementary sources are understood. Response planning should consider appropriate restrictions on the downstream consumption of PNT information to limit the impact of PNT disruptions. Define the incident types, resources, and management support needed to effectively maintain and mature the incident response and contingency capabilities. For critical applications and where practical, identify all known PNT system and component fault and failure modes within the deployed environments with the objective of increasing the probability that at least one PNT source will not be susceptible to each failure mode identified. For each failure and fault mode, identify detection and compensation strategies, effects on the computed PNT data, and effects on the applications dependent on the data to determine whether	**ICAO 9849** 1.5 **IEC 61850-90-12** 5.8 **IEEE 2030.101** 4.12-4.14 **ITU-T 8262** 11 **IMO 1575** E.4 **ITU-T 8275** 7.2 **NIST JRES** 120.017 **NIST SP 800-53 Rev. 5** CP-1, CP-2, CP-7, CP-10, CP-12, CP13, IR-1, IR-7, IR-8, IR-9, PE-17 **NIST SP 800-160 Rev.1** Appendix F.2.6 **RTCA 356** 5.6.6 **USG FRP** 1.7.3, 6

Protect Information Protection Processes and Procedures		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	the response and recovery plans are adequate to meet business continuity objectives. Implement mitigation strategies to temporary PNT disruptions and manipulations for all critical services. A means to maintain business continuity is leveraging complementary and holdover PNT sources and redundant components, such as antennas spaced sufficiently apart and high-stability oscillators. Select, use, and ensemble PNT sources based on system priority classifications to meet business continuity objectives. Identify complementary PNT sources with multiple phenomenologies and an understanding of the benefits, limitations, and dissimilar failure modes to increase the probability that the PNT service is able to detect anomalous inputs and remain available in contested environments. For responses to PNT data-dependent critical functions that involve failures or shutdowns, define and execute fail-secure or fail-safe plans for PNT systems and components. Perform PNT system acceptance testing to verify and validate response and recovery plans. For example, for systems with redundant or complementary time sources, validate current system time delivered via a time distribution protocol by removing the primary time source and confirming that the time accuracy and precision, as well as any phase or frequency steps or ramps, are in accordance	

Protect Information Protection Processes and Procedures		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	with predefined clock requirements for the time server and downstream applications. Consider the creation and maintenance of developmental and operational test and evaluation methods to assess, verify, and validate PNT service performance under normal and contested conditions.	
IP-10: **Response and recovery plans are tested.**	Assess threat preparedness by verifying incident response and recovery plans of the PNT systems. For critical applications, consider qualification and periodic testing to assess PNT response and recovery plans for infrequent events (e.g., leap seconds) or changes to the components or operations that would significantly impact the performance for the system. Review the results to determine the efficiency and effectiveness of the plans as well as readiness to execute the plans. Use the results of the tests to inform other CSF functions, such as "Detect." Exercise the response and recovery plans to validate that the effects of the anomalous events on the PNT data's availability, integrity, and continuity are within specified tolerances. For example, for systems with redundant or complementary time sources, validate current system time delivered via a time distribution protocol by removing the primary time source and confirming that the time accuracy and precision, as well as any phase or frequency steps or ramps, are in accordance with pre-defined clock requirements for the time server and downstream	**DHS RCF** 8 **DHS ST** **ICAO 9849** 5.3.2.2 **IEC 61850-90-4** 14.2.4 **IEEE 2030.101** 5.4.2.5 **ITU-T GNSS** Appendix VII.3, VII.4 **NERC GridEx** **NIST SP 800-53 Rev. 5** CP-4, IR-3, PM-14 **RTCA 229** 2 **RTCA 326** 3.4.2, 3.4.4 **Teasley 1995**

Protect Information Protection Processes and Procedures		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	applications. Testing response and recovery plans may include the use of RF signals to simulate anomalous events. Any simulation that involves RF transmissions must be done in in a manner that is consistent with industry best practices and in accordance with laws and regulations.	

4.2.5 Maintenance Category

Maintenance and repairs of industrial control and information system components are performed consistent with policies and procedures. In the context of this PNT Profile, the systems and components of interest include GNSS receivers, antennas, modules, and time servers.

Both Subcategories within the Maintenance Category apply to the PNT Profile, as summarized in the table below.

Table 12 - Maintenance Subcategories Applicable to PNT

Protect Maintenance		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
MA-1: **Maintenance and repair of organizational assets are**	Schedule, perform, record, and review records of maintenance and repairs on PNT devices and components.	**DHS CISA** 4 **DHS GPS CI** **DHS RCF** 8

Protect **Maintenance**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
performed and logged, with approved and controlled tools.	Assess the impacts of the maintenance and repair of the PNT devices and components on the end user's operations and verify that the PNT devices and components perform within specified tolerances. Infrequent events, such as leap seconds, may be handled differently by different sources of PNT. Understand how these events and their implementations impact operations. Make available and adhere to documentation and artifacts, such as software maintenance procedures, configuration parameters (including default values and ranges), test plans, compliance test result documentation, and other pertinent information to ensure consistent and valid deployments. Document PNT system and component calibration procedures and results for applications that require legal traceability or known uncertainty. The frequency of calibrations is dependent on factors such as environmental conditions, changes in PNT systems, components and architecture, exposure to disruptions and manipulations, and PNT data performance requirements. Calibration procedures may include the absolute or relative calibration or recalibration of components. Document procedures for minimum periodic calibrations to a standard reference, particularly for applications that require traceability. For example, in the U.S., legal or absolute time	**DHS TFS** 1.6, 2, 3.6, 3.8 **IEEE 1588** Annex N **IEEE 2030.101** 4.7, 6 **IETF 8633** 3.1 **ITU-T GNSS** 2 **NIST SP** 250-29 **NIST SP 800-53 Rev. 5** MA-1, MA-2, MA-3, MA-5, MA-6 **NIST SP 1065** 5-10 **Levine 2021**

Protect **Maintenance** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	calibration requires an unbroken chain of documented calibrations to UTC(NIST) or UTC(USNO). Delay variations and the stability of each component due to factors such as temperature or aging should be characterized in the environment in which the PNT system will be deployed. The calibration of component delays (e.g., antenna, surge suppressors, cables, connectors, splitters, receivers, switches) should be recorded to verify that the absolute accuracy and precision in the end-to-end systems that form and use PNT data are within specified tolerances.	
MA-2: **Remote maintenance of organizational assets is approved, logged, and performed in a manner that prevents unauthorized access.**	Enforce approval requirements, control, and monitoring of remote maintenance activities. Employ the appropriate level of authentication, least privilege, logging, record keeping, and session termination for remote maintenance.	**DHS CISA** 4.b **DHS GPS CI** **IEEE 1588** Annex P.2.5.2 **IEEE 2030.101** 4.8.2, 4.15.2, 4.15.3, Annex G.2.4 **IETF 8633** 3.5, A.3 **NIST SP 800-53 Rev. 5** MA-4 **NIST SP 800-160 Rev. 1** Appendix F.1.14

4.2.6 Protective Technology Category

Technical security solutions are managed to ensure the security and resilience of systems and assets consistent with related policies, procedures, and agreements.

There are five Subcategories within the Protective Technology Category that apply to the PNT Profile, as summarized in the table below.

Table 13 - Protective Technology Subcategories Applicable to PNT

Protect **Protective Technology** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
PT-1: **Audit/log records are determined, documented, implemented, and reviewed in accordance with policy.**	Generate audit records that contain information such as what, when, the source, the outcome, and the identity of any individuals or PNT components associated with the event. Consider maintaining audit logs for extended periods to support forensic analysis. A log file should also include entries of proper working states in addition to entries of anomalies and events. Wherever practical, logging and audit mechanisms should produce data elements in accordance with standard data formats to facilitate parsing and consumption by analytic teams. PNT-dependent applications that require an audit trail often require legal or metrological traceability—an unbroken documented chain of calibrations—from a standard or other trusted reference. As part of characterizing the physical device using or forming PNT data, determine the delay characteristics	**DHS CISA** 7.a **DHS GPS CI** **DOT 12464** **IEEE 1588** 16.14.4.4.2 **Matsakis 2018** III, IV, V **NIST SP 800-53 Rev. 5** AU-1, AU-2, AU-3, AU-6, AU-7, AU-12, AU-13, AU-14, AU-16 **NIST SP 800-160 Rev. 1** 3.3.2, 3.3.5 **SEC 613**

Protect Protective Technology Subcategory	Applicability to PNT	References (PNT-Specific)
	between the device clock and the time stamping functions used for the audit and logs.	
PT-2: **Removable media is protected and its use restricted according to policy.**	Employ safeguards to restrict the use of portable media when used on PNT devices and components. Ensure that PNT devices and equipment follow organizational policy on removable media.	**NIST SP 800-53 Rev. 5** MP-1, MP-2, MP-3, MP-4, MP5, MP-7, MP-8
PT-3: **The principle of least functionality is incorporated by configuring systems to provide only essential capabilities.**	PNT deployment should employ the principle of least functionality. Configure the PNT system to provide only essential capabilities. When PNT data or services do not require functionality from intermediary nodes, they can be disabled to minimize attack surfaces.	**IEEE 1588** Annex P2.5.1,2.5.5 **IETF CMP** 6 **IETF 7384** 7.3 **NIST SP 800-53 Rev. 5** AC-3, CM-7
PT-4: **Communications and control networks are protected.**	Typically, PNT systems have high availability and integrity requirements. Identify communications and control network requirements for availability, integrity, authentication, stability, confidentiality, and other pertinent parameters based on classes of applications, and provide appropriate levels of protection. Observe cyber hygiene in communications and control networks.	**DHS CISA** 4.a, 5.a **DHS GPS CI** **IEEE 1588** 16.14.4.4.2, Annex P **IETF 8633** 4.4, 5.5, 5.6 **IETF NTS** 3 **ITU-T G.8275** 8 **NIST CSF** PR.PT-P3

Protect **Protective Technology** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	Consider appropriate measures for networks that distribute PNT data. Some measures need to be considered at the architectural phase of the SDLC, such as transport security implementations, while others can be applied at the configuration or deployment phase, such as transport security. For example, some NTP/PTP devices have multiple network ports that could be configured to isolate control traffic. As needed, consider transport security for networks that distribute PNT data. Note that implementing some transport security measures (e.g., use of cryptographic algorithms and implementations) can lead to time synchronization performance degradation that may be problematic, especially for high-precision timing applications. Verify that protective measures will not adversely affect the overall system performance requirements.	**NIST SP 800-53 Rev. 5** AC-12, AC-17, AC-18, CP-8, SC-5, SC-7, SC-10, SC-11, SC-20, SC-21, SC-22, SC-23, SC-31, SC-37, SC-38, SC-47 **NIST SP 800-160 Rev. 1** Appendix F
PT-5: **Mechanisms (e.g., failsafe, load balancing, hot swap) are implemented to achieve resilience requirements in normal and adverse situations.**	Mechanisms include proactive measures that reject bad PNT signals and data to limit how far threats penetrate into PNT systems. Reactive measures should also be present to handle threats that penetrate into PNT systems, including holdover capabilities paired with anomaly detection, features to limit performance degradation, and recovery capabilities.	**DHS RCF** 5-7 **IEEE 1588** 9.3, 16.4, 17 **NIST SP 800-53 Rev. 5** CP-7, CP-8, CP-11, CP-12, CP-13, PE-11, PL-8, SC-6 **USG FRP** 5.1

Protect Protective Technology Subcategory	Applicability to PNT	References (PNT-Specific)
	Resiliency measures can also be achieved through new system designs that limit exposure times to attack surfaces, protect internal states, and have intelligent control algorithms. Some mechanisms to consider in the design phase include leveraging PNT service providers with hardened signals, redundant PNT sources, fused PNT sources, or others in accordance with the resiliency requirements of the mission.	

4.3 Detect Function

The Detect Function addresses the development and deployment of appropriate activities to monitor for anomalous events and notify downstream users and applications upon their occurrence. The Detect Function is informed by the Identify Function and is enabled by the Protect Function.

The objectives of the Detect Function include:

- Enabling detection through monitoring and consistency checking; and
- Establishing a process for deploying and handling detected anomalies and events.

The Detect Function defines three Categories, all of which have Subcategories that apply to the PNT Profile to varying degrees, as summarized in Sections 4.3.1 through 4.3.3.

4.3.1 Anomalies and Events Category

Anomalous activity is detected, and the potential impact of events is understood. In the context of this PNT Profile, this includes the detection of uncharacteristic PNT data or a loss of PNT data for some period.

There are five Subcategories within Anomalies and Events that apply to the PNT Profile, as summarized in the table below.

Table 14 - Anomalies and Events Subcategories Applicable to PNT

Detect **Anomalies and Events** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
AE-1: **A baseline of network operations and expected data flows for users and systems is established and managed.**	Verify that operational PNT data performance baselines and expected data flows for relevant external PNT information systems, the organization's PNT system, and applications dependent on PNT data are captured, developed, and maintained to detect events. When practical, comply with standards-based solutions for data formatting, message formatting, and message transmission to facilitate interoperability and integration.	**DHS CISA** 1.d **GPS ICD-870** 3.1 **IEEE 1588** Annex J **IETF CMP** **IMO 1575** D, D.1, D.2 **NIST SP 800-53 Rev. 5** AC-4, CA-3, CM-2, SC-16, SI-4 **RTCA 229** 1.5.2, 1.7.2 **USG FRP** Appendix B
AE-2: **Detected events are analyzed to understand attack targets and methods.**	Review and analyze detected events within the PNT system in (i) real time to maintain normalcy of operations; and (ii) forensically to understand the characteristics (e.g., source, data error statistics, duration, frequency, and location) of anomalous events. Be able to identify potential cyber incidents and understand attack targets and methods.	**DHS GPS CI** **DHS RCF** 5.2 **Kaplan 2017** Chapters 9, 10 **NIST SP 800-53 Rev. 5** AU-6, CA-7, IR-4, RA-5, SI-4

Detect **Anomalies and Events** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	Be able to distinguish between potentially harmful events and normal operations. Be able to predict harm based on events. Consider the PNT system when analyzing cybersecurity events involving downstream applications. For RFI, include environmental monitoring with direction-finding capabilities to locate the source. Preserve the raw data, analysis, and characterization to aid in the analysis of future events.	**RTCA 229** Appendix R **RTCA 235** 2.1
AE-3: **Event data are collected and correlated from multiple sources and sensors.**	Multiple sensors and sources can be used to correlate fault modes and contribute to anomaly detection models and algorithms. PNT data from multiple sources may be used, cross-checked, and compared for the detection of anomalous behavior. Compile sufficient event data across the PNT system using various sources, such as event reports, logs, audit monitoring, network monitoring, physical access monitoring, environmental monitoring, and user and administrator reports. Standards-based data formatting and serialization promotes the communication interoperability and interchangeability of PNT data and supporting data.	**DOT CGSIC** **GPS ICD-870** 3.1 **ICAO 9849** 5.3.3.5, 7.11 **IEEE 1588** Annex J **IEEE 2030.101** 4.7, 4.8, 4.13, 5.4.4 **IETF CMP** **IMO 1575** 2, 3 **NAVCEN** **NIST SP 800-53 Rev. 5** AU-6, CA-7, CP-2, IR-4, IR-5, IR-8, SI-4

Detect **Anomalies and Events** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	Consider subscribing to or enabling user community and PNT provider communications for status on PNT data and services. Use authoritative sources of PNT data products, such as informational almanacs and status information, with authentication and data integrity verification capabilities. For GPS, NAVCEN has information on almanacs, operational advisories, NANU (Notice Advisory to Navstar Users), and CGSIC (Civil GPS Service Interface Committee) bulletins. Additional sector-specific advisories may be provided by ISACs and sector-specific agencies.	**NIST SP 800-160 Rev. 1** 3.3.7 **RTCA 229** Appendix G.2, G.3 **RTCA 235** 1.1 **USG FRP** Appendix
AE-4: **Impact of events is determined.**	Identify the effects of anomalous events on the PNT data and applications that are dependent on the PNT data. PNT events (including infrequent events and true anomalies) can have unexpected impacts on systems and operations downstream from PNT devices and equipment. Users should understand how such events might impact operations.	**DOT 12464** **NIST SP 800-53 Rev. 5** CP-2, IR-4, RA-3, SI-4 **RTCA 229** Appendix R
AE-5: **Incident alert thresholds are established.**	Established PNT incident thresholds and understanding potential impacts to the mission enables proper reporting, alerting thresholds, and the development of adequate incident alert procedures. For critical applications, document absolute or relative PNT data error and uncertainty tolerances that serve as detection thresholds, which can be expressed as a statistical distribution within the confidence levels needed for operations. For PNT-	**GPS SPS** 2.3.4 **ICAO 9849** 7.11 **IMO 1575** 2.2.1, Appendix C **NIST SP 800-53 Rev. 5** IR-4, IR-5, IR-8

Detect **Anomalies and Events**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	dependent applications, consider and document the required notification or alarm communication time upon nearing and exceeding thresholds. Based on mission requirements, consider reviewing and revising thresholds on a routine basis.	**USG FRP** Appendix A

4.3.2 Security Continuous Monitoring Category

The information system and assets are monitored to identify cybersecurity events and verify the effectiveness of protective measures. In the context of this PNT Profile, the interface to the PNT service provider, the receivers that process and form the PNT data, the intermediate nodes that transport PNT services, and the end applications consuming PNT data are monitored.

There are eight Subcategories within the Security Continuous Monitoring Category that apply to the PNT Profile, as summarized in the table below.

Table 15 - Security Continuous Monitoring Subcategories Applicable to PNT

Detect **Security Continuous Monitoring**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
CM-1:	Monitor the PNT source and associated information products, PNT distribution, PNT data output characteristics,	**DHS CISA** 1.d

Detect **Security Continuous Monitoring** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
The network is monitored to detect potential cybersecurity events.	and additional characteristics from applications and systems dependent on PNT data against known baseline characteristics to detect anomalies, including when PNT security measures may fail. Heighten system monitoring activities when there is an indication of increased risk. Use an effective mix and fusion of data from multiple, diverse PNT sources and PNT data distribution routes. Consider using fault detection and exclusion algorithms to automatically detect faults and exclude erroneous sources in the computation of data used to form or that is dependent upon PNT data. This enables redundancy and consistency checking to detect changes in propagation delays and other characteristics indicating compromises in PNT data. Verify that the monitoring strategy is sufficiently robust to detect PNT data and other system behavior anomalies for all identified fault and failure modes. Detection thresholds can be determined from nominal and anomalous data for each fault and failure mode. Consider relevant fault parameters and acceptance bounds based on reasonable or conservative criteria for various classes of applications and users. Detection models can leverage correlations between fault modes and minimum detectable limits. Analysis of the correlation engines may be able to determine if some faults	**DHS RCF** 7, 8 **DOT 12464** **ICAO 9849** 5.3.1.5-5.3.1.9, 7.8 **IEEE 1588** 16.11, 16.12, Annex J, P.2.4 **IEEE 2030.101** 4.5.2 **IETF CMP** **IMO 1575** C.2.2, Appendix C.1 **ITU-T GNSS** Appendix III, VI **NIST SP 800-53 Rev. 5** AU-12, CA-7, CM3, SC-5, SC-7, SI-4 **RTCA 229** 1.7.2, 1.7.3, 2.1.1.5, 2.1.3.2.2.3, 2.1.5.2.2, 2.2.1.6, 2.2.2.6 **RTCA 235** 2.3, 2.5 **USG FRP** Appendix B

Detect **Security Continuous Monitoring** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	can remain undetected. These findings can be used in the risk management procedures. Consider providing a loopback reference timing signal to continuously monitor for changes in the total network and signal propagation delay. Within a specified time, alert dependent users and applications when monitoring is unavailable or when PNT data or service is unavailable. Software and hardware can be integrated into the PNT system and critical infrastructure components to detect and mitigate GNSS jamming and spoofing events and preserve PNT data availability, continuity, and integrity.	
CM-2: **The physical environment is monitored to detect potential cybersecurity events.**	Physical access to PNT devices and components is actively monitored to detect potential breaches in security. Actively monitor the physical environment to include the RF environment. PNT devices and equipment may be in remote locations. Positively identify people who access areas that contain PNT devices. Where feasible, implement the use of access controls that are specific to personnel, such as swipe cards and personal identification numbers (PINs).	**DHS GPS CI** **ICAO 9849** 5.3.7 **Kaplan** 10 **NIST SP 800-53 Rev. 5** CA-7, PE-6, PE-20
CM-3: **Personnel activity is monitored to detect**	Monitor personnel actions for unauthorized activity on or using PNT systems or data. The scope of the monitoring can include elements such as login attributes (e.g., time, physical location, operating system, device, credentials), electronic	**NIST SP 800-53 Rev. 5** AC-2, AU-12, AU-13, CA-7, CM-10, CM-11

Detect **Security Continuous Monitoring** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
potential cybersecurity events.	access control systems, physical access control systems (e.g., sign in/out sheets, logging), security status monitoring of personnel activity associated with PNT systems, detecting software use, and installation restrictions.	
CM-4: **Malicious code is detected.**	Deploy malicious code detection mechanisms, such as behavioral anomaly detection tools, throughout the PNT systems to detect and eradicate malicious code. Should a PNT data consumer experience an anomaly, consider investigating the PNT system and associated applications as possible sources of the anomaly. Systems that use and support PNT data should be included in the antivirus analysis. Update malicious code protection mechanisms, such as antivirus protections, when new releases are available in accordance with the configuration management policy and procedures for the PNT systems involved.	**DHS CISA** 4.a **NIST SP 800-53 Rev. 5** SC-44, SI-3, SI-4, SI-8
CM-5: **Unauthorized mobile code is detected.**	PNT devices and equipment contain operating systems and may be vulnerable to unauthorized mobile code introduced by other vectors. Mobile code detection mechanisms throughout the enterprise are recommended because vulnerabilities' level of access may be inherited from other applications of the mobile code.	**DHS CISA** 4.a **NIST SP 800-53 Rev. 5** SC-18, SI-4, SC-44
CM-6:	Detect deviation from PNT service providers' interface specifications, which are defined in a service-level	**DOT CMPS** 3

Detect **Security Continuous Monitoring** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
External service provider activity is monitored to detect potential cybersecurity events.	agreement (SLA) with the service provider. This can include signal integrity, availability, continuity, and coverage. Consider subscribing to or enabling user community and PNT provider communications for status on PNT data and services. For example, NAVCEN has information on almanacs, Operational (OPS) Advisories, NANU (Notice Advisory to Navstar Users), and CGSIC (Civil GPS Service Interface Committee) bulletins. Additional sector-specific advisories may be provided by ISACs and sector-specific agencies.	**GPS IS-200** 3 **GPS IS-705** 3 **GPS IS-800** 3 **ICAO 9849** 7.8, 7.11 **IMO 1575** 2.2, B.1, E.1 **NAVCEN** **NIST SP 800-53 Rev. 5** CA-7, PS-7, SA-4, SA-9, SI-4 **USG FRP** Appendix B
CM-7: **Monitoring for unauthorized personnel, connections, devices, and software is performed.**	Conduct ongoing security status monitoring on PNT systems for unauthorized personnel, connections, devices, access points, and software. Monitor for system inventory discrepancies. Collect, aggregate, and analyze data from systems that use and support the generation and dissemination of PNT data to indicate potential unauthorized access or activity.	**NIST SP 800-53 Rev. 5** AU-12, CA-7, CM-3, CM-8, PE-6, PE-20, SI-4 **NTP MON**
CM-8: **Vulnerability scans are performed.**	Conduct vulnerability scans on PNT systems where safe, feasible, and in a manner that is consistent with industry best practices. Include analysis, remediation, and information sharing in the vulnerability scanning process. Ensure that scanning activities do not negatively impact online PNT devices and equipment operation.	**DHS CISA** 1.a **IEEE 2030.101** 5 **NIST SP 800-53 Rev. 5** RA-5 **NIST SP 800-115**

Detect **Security Continuous Monitoring**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	Vulnerability scanning may include the use of RF signals to simulate events such as jamming and spoofing. Any simulation that involves RF transmissions must be done in a responsible manner, according to manufacturer instructions, and in accordance with laws and regulations to avoid impacts on operations or to others. Monitor the PNT source, network distribution characteristics (e.g., delays, jitter, bandwidth saturation), signal distribution medium characteristics (e.g., timing delays), PNT data output, and additional characteristics from applications and systems that are dependent on PNT data for anomalous behavior, including when security measures may fail and the system needs to fail-secure or fail-safe. All sources of PNT, including alternate or complementary PNT devices, need to be tested and enabled in advance of a PNT disruption event.	**RTCA 229** 1.6.2, 1.7.2, 2.1.1.1.5, 2.4, 2.5 **RTCA 326** 3.4.4 **Teasley 1995**

4.3.3 Detection Processes Category

Detection processes and procedures are maintained and tested to ensure awareness of anomalous events. In the context of this PNT Profile, the process and procedures on the information systems and assets as well as the analytic processes and procedures are maintained, updated, and tested.

There are four Subcategories within the Detection Process Category that apply to the PNT Profile, as summarized in the table below.

Table 16 - Detection Processes Applicable to PNT

Detect **Detection Processes** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
DP-1: **Roles and responsibilities for detection are well-defined to ensure accountability**.	When feasible, provision roles and responsibilities within a cooperative detection framework for data collection, data storage, and data dissemination towards improving future PNT protection, detection, response, and recovery capabilities. Understand PNT service provider and sector specific PNT detection roles and responsibilities.	**DHS IDM** **DOT CMPS** 1.3 **ICAO 9849** 7.8 **NIST SP 800-53 Rev. 5** CA-2, CA-7, PM-14 **USG FRP** 2.1-2.4, 3.2.11
DP-3: **Detection processes are tested.**	Validate that event detection processes are operating as intended. PNT devices and components that are upgraded are re-validated with end-to-end testing by the users. Perform periodic testing to verify the performance of the detection process against the most current threat profiles and vulnerabilities	**DHS RCF** 6 **DHS ST** **NIST SP 800-53 Rev. 5** CA-2, CA-7. PM-14, SI-3, SI-4 **RTCA 229** 1.7.2, 1.7.3, 1.8.2.3, 2.1.1.4.1, 2.1.1.5, 2.1.1.13, 2.1.2.2, 2.1.3.2, 2.1.4.2, 2.1.4.9, 2.1.5.2, 2.4.1.1, 2.5.3, 2.5.7, 2.5.9-2.5.11 **RTCA 326** 3.4.4
DP-4:	Communicate PNT data anomaly detection and the current best estimate of PNT data quality to personnel, partners, analytics, and downstream application users.	**ICAO 9849** 7.12, Appendix F **IEEE 1588** 7.6.2, 16.11, 16.12

Detect **Detection Processes** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
Event detection information is communicated.	When the cause of a PNT service disruption event is suspected to be external, share event detection with the appropriate external stakeholders for further investigation.	**IEEE C37.238** 6.2.1, 6.3 **IETF CMP** **IMO 1575** 2.3, B.2.2.1 **ITU-T G.8275** Appendix II, IV **NIST SP 800-53 Rev. 5** AU-6, CA-2, CA-7, RA5, SI-4 **RTCA 229** 2.1.1.4 **USG FRP** Appendix B
DP-5: **Detection processes are continuously improved.**	Modify and improve the monitoring strategy as new fault modes are identified and until detection performance is acceptable. Periodically examine the organization's PNT anomaly detection processes and seek to improve them continuously.	**NIST SP 800-53 Rev. 5** CA-2, CA-5, CA-7, PL-2, PM-14, RA-5, SI-4

4.4 Respond Function

Develop and implement the appropriate activities to respond to a detected cybersecurity or anomalous event. The activities in the Respond Function support the ability to contain the impacts of a disruption or manipulation to PNT services or data.

The Respond Function serves as a list of recommended actions and is triggered by the outputs generated by the Detect Function. The Protect Function provides the ability for the Respond Function to execute the proper response to an event according to a predefined plan.

The objectives of the Response Function are to:

- Contain PNT events using a verified response procedure;
- Communicate the occurrence and impact of the event on PNT data to PNT data users, applications, and stakeholders;
- Develop processes to respond to and mitigate new known or anticipated threats or vulnerabilities; and
- Evolve response strategies and plans based on lessons learned.

The Respond Function within the Cybersecurity Framework defines five Categories, all of which have at least one Subcategory that applies to the PNT Profile to varying degrees, as summarized in Sections 4.4.1 through 4.4.5.

4.4.1 Response Planning Category

Response processes and procedures are executed and maintained after detected cybersecurity incidents.

There is one subcategory within Response Planning that applies to the PNT Profile, as summarized in the table below.

Table 17 - Response Planning Subcategory Applicable to PNT

Respond **Response Planning** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
RP-1: **Response plan is executed during or after an incident.**	Execute the response plan during or after a cybersecurity event that affects PNT systems in accordance with the predefined threshold. Document the steps and results of the response plans as they are being executed. Include categories of incidents and PNT resilience level requirements based on application criticality and impact. Update the response plans to address changes to the organization, such as PNT system, attack vectors,	**DHS RCF** 5.3, 5.4, 6 **IMO 1575** C.2.1, C.2.2 **NIST SP 800-53 Rev. 5** CP-2, CP-10, IR-4, IR-8

Respond Response Planning		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
	environment of operation, and problems encountered during plan implementation, execution, and testing.	

4.4.2 Communications Category

Response activities are coordinated with internal and external stakeholders (e.g., external support from law enforcement agencies). In the context of this PNT Profile, external stakeholders may include sources that announce events that will impact the PNT service, such as PNT interference or corrections for leap seconds.

There are four Subcategories within the Communications Category that apply to the PNT Profile, as summarized in the table below.

Table 18 - Communications Subcategories Applicable to PNT

Respond Communications		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
CO-1: **Personnel know their roles and order of operations when a response is needed.**	Ensure that personnel are trained to respond to PNT disruptions and manipulations and understand recovery time objectives (RTO), recovery point objectives (RPO), restoration priorities, task sequences, and assignment responsibilities for event response programs and processes in a manner that is consistent with business continuity objectives.	**DHS CISA** 1.f, 7.a **DHS RCF** 5.2, 8.3 **IMO 1575** C.2.2 **NIST SP 800-61**

Respond Communications Subcategory	Applicability to PNT	References (PNT-Specific)
		NIST SP 800-34 Rev.1 3.2.1, CP-2, CP-3, IR-3, IR-8 **NIST SP 800-53 Rev. 5** CP-2, CP-3, IR-3, IR-8 **USG FRP** 5.1.2.5
CO-2: **Incidents are reported consistent with established criteria.**	Ensure that cybersecurity events on the PNT system are reported in a manner consistent with the response plan. Suspected intentional interference should be reported to stakeholders through the appropriate channels and procedures. For example, suspected land-based RFI can be reported to NAVCEN, NASA Aviation Safety Reporting System for aeronautics, or NERC E-ISAC for the electric utility sector.	**DHS IDM** **ICAO 9849** 7.12, Appendix F 6.1.1 **NAVCEN** **NIST SP 800-53 Rev. 5** AU-6, IR-6, IR-8 **NIST SP 800-61 Rev. 2** 4 **NERC CIP-008-6** **NERC EISAC** **USG FRP**
CO-3: **Information is shared consistent with response plans.**	Share cybersecurity incident information with relevant stakeholders as defined in the organizational sharing policies.	**DHS CISA** 1.d, 1.f **DHS IDM** **FCC**

Respond Communications Subcategory	Applicability to PNT	References (PNT-Specific)
	Where feasible, consider enabling PNT systems and PNT data information sharing to alert downstream users and applications of a disruption or manipulation of PNT data, allowing applications and users to respond in near real-time based on application tolerances.	**ICAO 9849** 7.12, Appendix F 6.1.1 **IEEE 1588** 7.6.2, 16.11, 16.12 **IETF CMP** **NAVCEN** **NERC EISAC** **NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8 **NIST SP 800-61 Rev. 2** 2.4
CO-4: **Coordination with stakeholders occurs consistent with response plans.**	In the event of PNT disruption or manipulation, coordinate PNT cybersecurity incident response actions with all relevant stakeholders in accordance with predefined agreements. When agreed upon between stakeholders, common data formats facilitate information sharing to strengthen the protection of the user community.	**DHS IDM** **NERC EISAC** **NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8, PE-6 **NIST SP 800-61 Rev. 2** 2.4

4.4.3 Analysis Category

Analysis is conducted to verify effective response and support recovery activities. In the context of this PNT Profile, the analysis will include the direct recipients of PNT services as well as secondary or downstream effects.

There are five Subcategories within the Analysis Category that apply to the PNT Profile, as summarized in the table below.

Table 19 - Subcategories Applicable to PNT

Respond **Analysis** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
AN-1: **Notifications from detection systems are investigated.**	Investigate cybersecurity-related notifications generated from PNT anomaly detection systems. Identify and locate potential sources of RFI. After determining that the source of a PNT data anomaly is external to the organization's system, partner with the appropriate external stakeholders for further investigation. DHS coordinates the development, implementation, and exercise of procedures to enable federal agencies with assigned responsibilities, authorities, and jurisdictions to investigate and mitigate GNSS-based PNT interference. Should multiple sensors report data anomaly events, analytics can be used to determine if the events are correlated or otherwise traced to a common causal agent.	**DHS IDM** **ICAO 9849** Appendix F 6.2 **NIST SP 800-53 Rev. 5** AU-6, CA-7, IR-4, IR-5, PE-6, RA-5, SI-4 **RTCA 235** 14.1.2
AN-2: **The impact of the incident is understood.**	Understand the full implication of a cybersecurity incident based on thorough investigation and analysis results. Consider the organizational impacts on PNT services that may affect downstream applications, users, and systems that are dependent on PNT. Understand downstream impacts and relationships through leveraging mapped services and outlined policies.	**ITU-T G.8275.1** Annex D **NIST SP 800-53 Rev. 5** CP-2, IR-4, RA-3 **NIST SP 800-61 Rev. 2** 3

Respond **Analysis** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
	Understand the scope and necessary actions required for remediation.	
AN-3: **Forensics are performed.**	Conduct forensic analysis on collected cybersecurity event information to determine if the adversary left a footprint or if there are any residual effects to the system. Conduct forensic analysis to aid in the determination of the root cause of PNT disruption or manipulation.	**ICAO 9849** Appendix F 6.2 **NIST SP 800-53 Rev. 5** AU-7, IR-4 **NIST SP 800-61 Rev. 2** 3
AN-4: **Incidents are categorized consistent with response plans.**	Categorize cybersecurity incidents according to the level of severity and impact consistent with the response plan.	**NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-5, IR-8, RA-3 **NIST SP 800-61 Rev. 2** 2 3.2
AN-5: **Processes are established to receive, analyze, and respond to vulnerabilities disclosed to the organization from internal and external sources (e.g., internal testing, security bulletins, or security researchers).**	For PNT components and applications that are dependent on PNT data, identify verification and validation procedures and processes for anticipated and known threats in response to existing and newly identified PNT fault and failure modes, including interfering signals, natural phenomena, and internal system failures. Reference available public and private trusted sources of threat and vulnerability intelligence information as it relates to PNT. Update PNT disruption event characterization documentation as well as organization or industry-shared databases to track the observed probability of occurrence in	**DHS RCF** 7, 8 **DOT 12464** **GPS-ICD-240** **ICAO 9849** 7.6, 7.7 **NCCIC** **NIST SP 800-53 Rev. 5** CA-1, CA-2, PM-4, PM-15, RA-1, RA-7, SI-5, SR-6 **NIST SP 800-61 Rev. 2** 3, 3.2 **NIST SP 800-160 Rev. 1** 3.4.9, 3.4.11

Respond Analysis Subcategory	Applicability to PNT	References (PNT-Specific)
	order to continuously update the risk assessment and response plans. Analyze the impact of the PNT data anomaly on user and application errors. Characterize nominal and anomalous PNT data from the incident for improving future monitoring and detection.	**NTP SEC** **RTCA 326** 3.4.4 **RTCA 356** 3.8 **USG FRP** Appendix B

4.4.4 Mitigation Category

Activities are performed to contain an event, mitigate its effects, and resolve the incident. In the context of PNT, mitigation measures may include failover to alternate or a fusion of PNT sources, notification to or from external stakeholders of ongoing PNT anomalies, and other activities.

There are three Subcategories within the Mitigation Category that apply to the PNT Profile, as summarized in the table below.

Table 20 - Mitigation Subcategories Applicable to PNT

Respond **Mitigation** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
MI-1: **Incidents are contained.**	Contain cybersecurity incidents to minimize impacts on the PNT system. Containment of a PNT event may require notification of downstream users and the transition to alternate or complementary PNT sources in accordance with resiliency level requirements and the business continuity plan for containment.	**DHS GPS CI** **NIST SP 800-53 Rev. 5** IR-4 **NIST SP 800-61 Rev. 2** 3.4.1
MI-2: **Incidents are mitigated.**	Given successful containment measures, implement PNT-based mitigation measures that can include alternate or complementary sources in order to operate through the incident. Once the effects of the incident are contained, take steps to return the PNT system to a proper working state. These steps may include the resetting, recalibration, and replacement of units in a manner that does not impact forensic efforts. Apply patches and updates to mitigate the vulnerability or incident. Mitigation procedures or measures should be part of the business continuity plan. Consider mitigation strategies such as PNT source and data path redundancy, diversity, and segmentation to minimize the impacts of PNT disruption or manipulation.	**3GPP TR22.878** 4, 5 **DHS GPS CI** **DHS RCF** 5.3, 5.4 **IMO 1575** C.2.1, C.2.2 **ITU-T G.8262** 11 **ITU-T G.8272** 7 **Kaplan** 1.8, 13 **NIST SP 800-53 Rev. 5** IR-4 **NIST SP 800-61 Rev. 2** 3.4 **NTP SEC** **USG FRP** 4

Respond Mitigation Subcategory	Applicability to PNT	References (PNT-Specific)
	Complementary or alternative PNT sources may include on-board sensors, clocks with acceptable holdover characteristics, other satellite constellations, signal frequencies, terrestrial RF sources (e.g., cellular, TBS), network-based PNT sources (e.g., NTP, PTP), and other signals of opportunity.	
MI-3: **Newly identified vulnerabilities are mitigated or documented as accepted risks.**	Risk assessments (refer to RA-1) should be updated with newly identified PNT vulnerabilities and mitigated or documented as acceptable risks. Maintain an RFI incident database in order to inform future mitigation strategies.	**NIST SP 800-53 Rev. 5** CA-2, CA-7, RA-3, RA-5, RA-5 **NIST SP 800-61 Rev. 2** 3 **NTP SEC** **RTCA 235** 14.1.4, 14.2-14.4 **RTCA 356** 3.8

4.4.5 Improvements Category

Organizational response activities are improved by incorporating lessons learned from current and previous detection and response activities. Both Subcategories within the Improvements Category apply to the PNT Profile, as summarized in the table below.

Table 21 - Improvements Subcategories Applicable to PNT

Respond **Improvements** **Subcategory**	**Applicability to PNT**	**References (PNT-Specific)**
IM-1: **Response plans incorporate lessons learned.**	PNT response plans incorporate lessons learned from ongoing incident handling activities into incident response procedures, training, and testing and implement the resulting changes accordingly.	**NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8 **NIST SP-800-61 Rev. 2**
IM-2: **Response strategies are updated.**	Enable a process for the response plan to evolve to reflect new threats, improved technology, and lessons learned. Analyze detected event information and incident responses to gain perspective on the impacts to the organization. Then correlate with and, if necessary, update the risk assessment. Determine preventative actions for fault modes by reviewing the identification, protection, and detection functions and updating as applicable. Revise protection, monitoring, detection, response, and recovery capabilities as needed to mitigate newly identified vulnerabilities in a timely manner. Industry standards may also need to evolve with new PNT capabilities, taking into account changes in threat models as well as technical, operational, and economic factors.	**DHS IDM** **DOT 12464** **ICAO 9849** 6.3, 6.4, 6.5, 6.7, 6.8, 6.9 **IMO 1575** E.1 **NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8 **NTP SEC** **RTCA 326** 3.4.1

4.5 Recover Function

The Recover Function develops and implements the appropriate activities to maintain plans for resilience and restore any capabilities or services that were impaired due to a cybersecurity event.

The activities in the Recover Function support timely recovery to normal operations and return the organization back to its proper working state after a disruption or manipulation of PNT services has occurred. The effectiveness of the Recover Function is dependent upon the implementation of the previous Functions—Identify, Protect, Detect, and Respond.

The objectives of the Recovery Function are to:

- Restore systems dependent upon PNT services to a proper working state using a verified recovery procedure;
- Communicate the recovery activities and status of the PNT services to PNT data users, applications, and stakeholders; and
- Evolve recovery strategies and plans based on lessons learned.

The Recover Function within the Cybersecurity Framework defines three Categories. Other than identify appropriate PNT sources, all of these Categories and Subcategories correlate with all of the components of the EO.

4.5.1 Recovery Planning Category

Recovery processes and procedures are executed and maintained to restore systems or assets affected by cybersecurity incidents to a proper working state.

There is one Subcategory within Recovery Planning that applies to the PNT Profile.

Table 22 - Recovery Planning Subcategory Applicable to PNT

Recover Recovery Planning Subcategory	Applicability to PNT	References (PNT-Specific)
RP-1: **Recovery plan is executed during or after a cybersecurity incident.**	The business continuity plan should include a recovery plan. Execute the recovery plan during or after a cybersecurity incident on the PNT system. Restore the PNT system within a predefined, acceptable time period from configuration-controlled and integrity-protected information representing a known, operational state for the components. Perform system acceptance testing. The recovery plan can include specific actions for restoration, recalibration, resetting, and test validation of equipment.	**DHS RCF** 5, 6 **ICAO 9849** 7.7 **IEEE 2030.101** 5 **NIST SP 800-34 Rev. 1** **NIST SP 800-53 Rev. 5** CP-10, IR-4, IR-8 **NIST SP 800-160 Rev. 1** 3.4.11, Appendix F.2.6 **NIST SP 800-184** **RTCA 229** 2.4, 2.5

4.5.2 Improvements Category

Recovery planning and processes are improved by incorporating lessons learned into future activities. In the context of this PNT Profile, the efficacy of the recovery actions, such as restoration of the PNT system, test plans, user notification and failover, are evaluated and improved should a similar event occur.

There are two Subcategories within the Improvements Category that apply to the PNT Profile, as summarized in the table below.

Table 23 - Improvements Subcategories Applicable to PNT

Recover Improvements Subcategory	Applicability to PNT	References (PNT-Specific)
IM-1: **Recovery plans incorporate lessons learned.**	PNT recovery plans incorporate lessons learned from ongoing incident handling activities into incident recovery procedures, training, and testing and implement the resulting changes accordingly. Update the vulnerability, threat, impact, and risk assessment. The data and resulting analysis will assist in the analyses of future events, updating risk assessments, and the development of monitoring, detection, response, and recovery features.	**DOT 12464** **NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8 **NIST SP 800-61 Rev. 2** 3.4 **NTP SEC**
IM-2: **Recovery strategies are updated.**	Update the recovery plan to incorporate lessons learned, reflect new threats, improve technology, and address changes to the organization, PNT system, operating environment, and problems encountered during plan implementation, execution, and testing. Recovery timeliness and prioritization based on application criticality are key to reducing impacts. Evaluate incident characteristics to determine the optimal recovery strategy and revise the recovery plan as needed.	**NIST SP 800-53 Rev. 5** CP-2, IR-4, IR-8 **NIST SP 800-61 Rev. 2** 3.4 **RTCA 326** 3.4.1

4.5.3 Communications Category

Restoration activities are coordinated with internal and external parties. In the context of this PNT Profile, external parties may include industry associations that provide insight with respect to how PNT services are restored after a PNT event, such as RFI. Restoration activities can include corrections for anomalies, calibrations, verification, and validation procedures.

There are three Subcategories within the Communications Category that apply to the PNT Profile, as summarized in the table below.

Table 24 - Communications Subcategories Applicable to PNT

Recover **Communications**		
Subcategory	**Applicability to PNT**	**References (PNT-Specific)**
CO-1: **Public relations are managed.**	Centralize and coordinate information distribution and manage the public-facing representation of the organization. Public relations management may include managing media interactions, creating privacy policies, coordinating and logging all requests for interviews, handling and 'triaging' phone calls and email requests, matching media requests with appropriate and available internal experts who are ready to be interviewed, screening all of the information provided to the media, and ensuring that personnel are familiar with public relations.	**NIST SP 800-34 Rev. 2** 4 **NIST SP 800-53 Rev. 5** IR-4 **NIST SP 800-184** 2.4
CO-2: **Reputation is repaired after an incident.**	Employ a crisis response strategy to protect against negative impacts and repair organizational reputation. Crisis response strategies may include actions to shape attributions of the crisis, change perceptions of the organization in crisis, and reduce the negative effects generated by the crisis.	**NIST SP 800-53 Rev. 5** IR-4 **NIST SP 800-184** (all sections)
CO-3: **Recovery activities are communicated to internal and external stakeholders**	Communicate recovery activities to all relevant internal and external stakeholders, executive teams, and management teams.	**DOT 12464** **DHS ST** **NIST SP 800-34 Rev. 2** **NIST SP 800-53 Rev. 5** CP-2, IR-4

Recover Communications Subcategory	Applicability to PNT	References (PNT-Specific)
as well as executive and management teams.		**NIST SP 800-184** **NTP SEC**

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Appendix A—Acronyms and Abbreviations

Selected acronyms and abbreviations used in this document are defined below.

Term	Definition
CISA	Cybersecurity and Infrastructure Security Agency
CRPA	controlled reception patterned antenna
CSF	Cybersecurity Framework
DHS	Department of Homeland Security
DOT	Department of Transportation
EISAC	Electricity Information Sharing and Analysis Center
EO	Executive Order
FCC	Federal Communications Commission
FPGA	field-programmable gate array
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	human machine interface
ICS	industrial control system
IDM	interference detection and mitigation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMO	International Maritime Organization
IoT	Internet of Things
IRIG	Inter-range Instrumentation Group Time Code
IRIG-B	Inter-range Instrumentation Group Time Code B
ISAC	Information Sharing and Analysis Center
ISO	International Organization for Standardization
ITRS	International Terrestrial Reference System
ITU-T	International Telecommunication Union International Telecommunications Standardization Sector
NANU	Notice Advisory to NAVSTAR Users
NASA	National Aeronautics and Space Administration
NAVCEN	U.S. Coast Guard Navigation Center
NCCIC	National Cybersecurity and Communications Integration Center
NERC	North American Electric Reliability Corporation
NGS	National Geodetic Survey

Term	Definition
NIST	National Institute of Standards and Technology
NOTAM	Notice to Airmen
NTP	Network Time Protocol
NTP SEC	NTP Security Notice
OEM	original equipment manufacturer
PII	personally identifiable information
PIN	personal identification number
PNT	positioning, navigation, and timing
PNT Profile	Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing (PNT) Services
PPS	pulse per second
PTP	Precision Time Protocol
RAIM	receiver autonomous integrity monitoring
RF	radio frequency
RFC	request for comments
RFI	radio frequency interference
RTO	recovery time objectives
SCADA	Supervisory Control and Data Acquisition
SLA	service-level agreement
SP	Special Publication
SPS	Standard Positioning Service
TBS	Terrestrial Beacon System
USG FRP	U.S. Government Federal Radionavigation Plan
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
VPN	virtual private network
WAAS	Wide Area Augmentation System
WLAN	wireless local area network
WGS-84	World Geodetic System – 1984

Appendix B—Glossary

Selected terms used in this document are defined below.

Accuracy (Absolute): The degree of conformity of a measured or calculated value to the true value, typically based on a global reference system. For time, the global reference can be based on the following time scales: UTC, TAI, or GPS. For position, the global reference can be WGS-84.

Accuracy (Relative): The degree of agreement between measured or calculated values among the devices and applications dependent on the position, navigation, or time data at an instant in time**.**

Allan deviation: A non-classical statistic used to estimate stability. The NIST equation for the Allan deviation (with non-overlapping samples) is

$$\sigma_y(\tau) = \sqrt{\frac{1}{2(M-1)}\sum_{i=1}^{M-1}(\bar{y}_{i+1} - \bar{y}_i)^2}$$

where $\bar{y}_i$ is the i^{th} of M frequency offset averages over the observation period, τ. Or

$$\sigma_y(\tau) = \sqrt{\frac{1}{2\tau^2(N-2)}\sum_{i=1}^{N-2}(x_{i+2} - 2x_{i+1} + x_i)^2}$$

where x_i is a series of phase offset measurements in time units that consists of individual measurements, x_1, x_2, x_3, and so on, N is the number of values in the x_i series, and the data are equally spaced in intervals τ seconds long.

The confidence interval of an Allan deviation estimate is dependent on the noise type but is often estimated as $\frac{\sigma_y(\tau)}{\sqrt{N}}$. [NIST T&F Glossary, Adapted] [NIST SP 1065, Adapted]

Atomic Clock: A clock referenced to an atomic oscillator. Only clocks with an internal atomic oscillator qualify as atomic clocks. [NIST T&F Glossary, Adapted]

Atomic Oscillator: An oscillator that uses the quantized energy levels in atoms or molecules as the source of its resonance. The laws of quantum mechanics dictate that the energies of a bound system, such as an atom, have certain discrete values. An electromagnetic field at a particular frequency can boost an atom from one energy level to a higher one, or an atom at a high energy level can drop to a lower level by emitting energy. The resonance frequency, f_o, of an atomic oscillator is the difference between the two energy levels divided by Planck's constant, h.

The principle underlying the atomic oscillator is that since all atoms of a specific element are identical, they should produce exactly the same frequency when they absorb or release energy. In theory, the atom is a perfect "pendulum" whose oscillations are counted to measure a time interval. The national frequency standards developed by NIST and other laboratories derive their resonance frequency from the cesium atom and typically use cesium fountain technology. Rubidium oscillators are

the lowest priced and most common atomic oscillators, but cesium beam and hydrogen maser atomic oscillators are also sold commercially in much smaller quantities. [NIST T&F Glossary]

Attack: Any kind of malicious activity that attempts to collect, disrupt, deny, degrade, or destroy information system resources or the information itself. [CNSSI 4009]

Availability (PNT): The availability of a PNT system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that PNT signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the PNT service provider. [USG FRP Appendix E, Adapted]

Calibration: A comparison between a device under test and an established standard, such as UTC(NIST). When the calibration is finished, it should be possible to state the estimated time offset and/or frequency offset of the device under test with respect to the standard, as well as the measurement uncertainty. Calibrations can be absolute or relative. Absolute calibrations are not biased by the calibration reference and would, therefore, be more reproducible. However, absolute calibrations can be more complex to determine. The bias in relative calibrations would be consistent if all the devices in the system are calibrated against the same calibration reference. Calibrations may also be performed relative to other devices without reference to an absolute standard. Relative calibrations are generally simpler to perform than absolute calibrations. [NIST T&F Glossary, Adapted]

Characterization: An extended test of the performance characteristics of a clock or oscillator. A characterization involves more work than a typical calibration. The device under test is usually measured for a long period of time (days or weeks), and sometimes, a series of measurements is made under different environmental conditions. A characterization is often used to determine the types of noise that limit the uncertainty of the measurement and the sensitivity of the device to environmental changes. [NIST T&F Glossary]

Clock: A device that generates periodic, accurately spaced signals for timekeeping applications. A clock consists of at least three parts: an oscillator, a device that counts the oscillations and converts them to units of time interval (such as seconds, minutes, hours, and days), and a means of displaying or recording the results. [NIST T&F Glossary]

Component: A hardware, software, firmware part or element of a larger PNT system with well-defined inputs and outputs and a specific function. [NIST SP 800-160, Adapted][DHS RCF, Adapted]

Confidentiality: Preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information. [NIST FIPS 200]

Continuity: The probability that the specified PNT system performance will be maintained for the duration of a phase of operation, presuming that the PNT system was available at the beginning of that phase of operation. [USG FRP]

Coverage: The surface area or space volume in which the signals are adequate to permit the user to determine a position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors that affect signal availability. [USG FRP]

Cybersecurity: Prevention of damage to, protection of, and restoration of computers, electronic communications systems, electronic communications services, wire communication, and electronic communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation. For example, PNT data is generated by cyber systems. Protection of the devices and systems used to generate PNT data should be considered part of cybersecurity. [NIST SP 800-53]

Delay (Path Delay): The [signal] delay between a transmitter and a receiver. Path delay is often the largest contributor to time transfer uncertainty. For example, consider a radio signal broadcast over a 1000 km path. Since radio signals travel at the speed of light (with a delay of about 3.3 μs/km), we can calibrate the 1000 km path by estimating the path delay as 3.3 ms and applying a 3.3 ms correction to our measurement. Sophisticated time transfer systems, such as GPS, automatically correct for path delay. The absolute path delay is not important to frequency transfer systems because on-time pulses are not required, but variations in path delay still limit the frequency uncertainty. [NIST T&F Glossary, Adapted]

Disciplined Oscillator (DO): An oscillator whose output frequency is continuously adjusted (often through the use of a phase locked loop) to agree with an external reference. For example, a GPS disciplined oscillator (GPSDO) usually consists of a quartz or rubidium oscillator whose output frequency is continuously adjusted to agree with signals broadcast by the GPS satellites.

Frequency: The rate of a repetitive event. If T is the period of a repetitive event, then the frequency f is its reciprocal, $1/T$. Conversely, the period is the reciprocal of the frequency, $T = 1 / f$. Because the period is a time interval expressed in seconds (s), it is easy to see the close relationship between time interval and frequency. The standard unit for frequency is the hertz (Hz), defined as the number of events or cycles per second. The frequency of electrical signals is often measured in multiples of hertz, including kilohertz (kHz), megahertz (MHz), or gigahertz (GHz). [NIST T&F Glossary]

Frequency Accuracy: The degree of conformity of a measured or calculated frequency to its definition. Because accuracy is related to the offset from an ideal value, frequency accuracy is usually stated in terms of the frequency offset. [NIST T&F Glossary]

Frequency Drift: An undesired progressive change in frequency with time. Frequency drift can be caused by instability in the oscillator and environmental changes, although it is often hard to distinguish between drift and oscillator aging. Frequency drift may be in either direction (resulting in a higher or lower frequency) and is not necessarily linear. [NIST T&F Glossary]

Frequency Offset: The difference between a measured frequency and an ideal frequency with zero uncertainty. This ideal frequency is called the nominal frequency. [NIST T&F Glossary]

Frequency offset can be measured in either the frequency domain or the time domain. A simple frequency domain measurement involves directly counting and displaying the output frequency of the device under test with a frequency counter. The frequency offset is calculated as

$$f_{off} = \frac{f_{meas} - f_{nom}}{f_{nom}}$$

where f_{meas} is the reading from the frequency counter, and f_{nom} is the specified output frequency of the device under test.

Frequency offset measurements in the time domain involve measuring the time difference between the device under test and the reference. The time interval measurements can be made with an oscilloscope or a time interval counter. If at least two time interval measurements are made, frequency offset can be estimated as

$$f_{off} = -\frac{\Delta t}{T}$$

where Δt is the difference between time interval measurements (phase difference), and T is the measurement period. [NIST T&F Glossary, Adapted]

Frequency Stability: The degree to which an oscillating signal produces the same frequency for a specified interval of time. It is important to note the time interval—some devices have good short-term stability while others have good long-term stability. Stability does not determine whether the frequency of a signal is right or wrong. It only indicates whether that frequency stays the same. The Allan deviation is the most common metric used to estimate frequency stability, but several similar statistics are also used. [NIST T&F Glossary]

Global Navigation Satellite System (GNSS): GNSS collectively refers to the worldwide positioning, navigation, and timing (PNT) determination capability available from one or more satellite constellations. Each GNSS system employs a constellation of satellites that operate in conjunction with a network of ground stations. Receivers and system integrity monitoring are augmented as necessary to support the required position, navigation, and timing performance for the intended operation. [USG FRP, Adapted] [ICAO 9849, Adapted]

GPS: The Global Positioning System (GPS) is a U.S.-owned utility that provides users with positioning, navigation, and timing (PNT) services. This system consists of three segments: the space segment, the control segment, and the user segment. The U.S. Space Force develops, maintains, and operates the space and control segments. [GPS GNSS]

Holdover: An operating condition of a clock which has lost its controlling reference input, is using its local oscillator, and can be augmented with stored data acquired while locked to the reference input or a frequency reference to control its output.

Integrity: A measure of the trust that can be placed in the correctness of the information supplied by a PNT service provider. Integrity includes the ability of the system to provide timely warnings to users when the PNT data should not be used. [USG FRP]

Interchangeable: The ability to combine signals from multiple PNT data sources into a single PNT solution, as well as the ability to provide a solution from an alternative source when a primary source is not available. [USG FRP]

Interference (electromagnetic): Any electromagnetic disturbance that interrupts, obstructs, degrades, or otherwise limits the performance of user equipment. [USG FRP, Appendix E]

Jamming (electromagnetic): The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing the effective use of a signal. [USG FRP, Appendix E]

Jitter: The short-term variations of the significant instants of a timing signal from their ideal positions in time (where short-term implies that these variations are of frequency greater than or equal to 10 Hz). [ITU-T 810]

Leap Second: A second added to Coordinated Universal Time (UTC) to make it agree with astronomical time to within 0.9 second. UTC is an atomic time scale based on the performance of atomic clocks. Astronomical time is based on the rotational rate of the Earth. Since atomic clocks are more stable than the rate at which the Earth rotates, leap seconds are needed to keep the two time scales in agreement. [NIST T&F Glossary, Adapted]

Multipath: The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion. [USG FRP, Appendix E]

Navigation: The ability to determine a current and desired position (relative or absolute) and apply corrections to course, orientation, and speed to attain a desired position. Navigation coverage requirements could be global, from sub-surface to surface and from surface to space. [DOT, Adapted]

Nominal Frequency: An ideal frequency with zero uncertainty. The nominal frequency is the frequency labeled on an oscillator's output. For this reason, it is sometimes called the nameplate frequency. For example, an oscillator whose nameplate or label reads 5 MHz has a nominal frequency of 5 MHz. The difference between the nominal frequency and the actual output frequency of the oscillator is the frequency offset. [NIST T&F Glossary]

Oscillator: An electronic device used to generate an oscillating signal. The oscillation is based on a periodic event that repeats at a constant rate. The device that controls this event is called a resonator. The resonator needs an energy source so it can sustain oscillation. Taken together, the energy source and resonator form an oscillator. Although many simple types of oscillators (both mechanical and electronic) exist, the two types of oscillators primarily used for time and frequency measurements are quartz oscillators and atomic oscillators. [NIST T&F Glossary]

PNT Data: All information used to form or disseminate PNT solutions, including signals, waveforms, and network packets.

PNT Solution: The full solution provided by a PNT system or source, including time, position, and velocity. A PNT system or source may provide a full PNT solution or a part of it. For

example, a GNSS receiver provides a full PNT solution, while a local clock provides only a timing or frequency solution. [DHS RCF]

PNT Source: A PNT system component that is used to produce a PNT solution. Examples include GNSS receivers, networked and local clocks, inertial navigation systems (INS), and timing services provided over a wired or wireless connection. [DHS RCF]

PNT System: The components, processes, and parameters that collectively produce the final PNT solution for the consumer. [DHS RCF]

Phase: The position of a point in time (instant) on a waveform cycle. A complete cycle is defined as the interval required for the waveform to retain its arbitrary initial value. [NIST T&F Glossary]

Phenomenologies: Physical phenomena such as radio frequencies, inertial sensors, and scene mapping, as well as diverse sources and data paths using those physical phenomena (e.g., multiple radio frequencies) to provide interchangeable solutions to users to ensure robust availability. [USG FRP]

Positioning: The ability to accurately and precisely determine one's location and orientation two-dimensionally (or three-dimensionally, when required) referenced to a standard reference frame, such as the World Geodetic System 1984, WGS84[G873], or ITRF2014. [DOT]

Precision: Refers to how closely individual PNT measurements agree with each other. [USG FRP]

Proper Working State: A condition in which the device or system contains no compromised internal components or data fields (e.g., data stored to memory) and from which the device or system can recognize and process valid input signals and output valid PNT solutions. An initial pre-deployment configuration is a basic example. The accuracy of the immediate PNT solution is not specified in this definition, as it will depend on the specifics of the device or system's performance and the degradation allowed by different resilience levels. [DHS RCF]

Reliability: The probability of performing a specified function without failure under given conditions for a specified period of time. [USG FRP]

Resilience: The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. [PPD-21]

Risk: A measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of: (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of occurrence. [NIST SP 800-37]

Risk Assessment: The process of identifying, estimating, and prioritizing risks to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation, resulting from the operation of an information system. Part of risk management incorporates threat and vulnerability analyses, and considers mitigations provided by security controls planned or in place. Synonymous with risk analysis. [NIST SP 800-30]

Risk Management: The program and supporting processes to manage information security risk to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation and includes (i) establishing the context for risk-related activities, (ii) assessing risk, (iii) responding to risk once determined, and (iv) monitoring risk over time. [NIST SP 800-39]

Risk Management Framework: The Risk Management Framework (RMF), presented in NIST SP 800-37, provides a disciplined and structured process that integrates information security and risk management activities into the system development life cycle. [NIST SP 800-37]

Secure: To reduce the risks of intrusions and attacks as well as the effects of natural or manmade disasters on critical infrastructure by physical means or defensive cyber measures. [PPD-21]

Short-Term Stability: The stability of a time or frequency signal over a short measurement interval, usually an interval of 100 seconds or less in duration. [NIST T&F Glossary]

Stability: An inherent characteristic of an oscillator that determines how well it can produce the same frequency over a given time interval. Stability does not indicate whether the frequency is right or wrong, but only whether it stays the same. The stability of an oscillator does not necessarily change when the frequency offset changes. An oscillator can be adjusted, and its frequency moved either further away from or closer to its nominal frequency without changing its stability at all.

The stability of an oscillator is usually specified by a statistic, such as the Allan deviation, that estimates the frequency fluctuations of the device over a given time interval. Some devices, such as an OCXO [Oven Controlled Crystal (Xtal) Oscillator] have good short-term stability and poor long-term stability. Other devices, such as a GPS disciplined oscillator (GPSDO), typically have poor short-term stability and good long-term stability. [NIST T&F Glossary, Adapted]

Synchronization: The process of setting two or more clocks to the same time. [NIST T&F Glossary]

Syntonization: The process of setting two or more oscillators to the same frequency. [NIST T&F Glossary]

Threat: Any circumstance or event with the potential to adversely impact organizational operations, organizational assets, individuals, other organizations, or the Nation through a system via unauthorized access, destruction, disclosure, modification of information, or denial of service. [NIST SP 800-53]

Traceability, Metrological: Property of a measurement result whereby the result can be related to a reference through a documented, unbroken chain of calibrations, each contributing to the measurement uncertainty. [VIM]

Time Interval: The elapsed time between two events. In time and frequency metrology, time interval is usually measured in small fractions of a second, such as milliseconds, microseconds, or nanoseconds. Higher resolution time interval measurements are often made with a time interval counter. [NIST T&F Glossary]

Time Scale: An agreed upon system for keeping time. All time scales use a frequency source to define the length of the second, which is the standard unit of time interval. Seconds are then counted to measure longer units of time interval, such as minutes, hours, or days. Modern time scales, such as UTC, define the second based on an atomic property of the cesium atom, and thus standard seconds are produced by cesium oscillators. Earlier time scales (including earlier versions of Universal Time) were based on astronomical observations that measured the frequency of the Earth's rotation. [NIST T&F Glossary]

Validation: Confirmation (through the provision of strong, sound, and objective evidence and demonstration) that requirements for a specific intended use or application have been fulfilled and that the system, while in use, fulfills its mission or business objectives while being able to provide adequate protection for stakeholder and mission or business assets, minimize or contain asset loss and associated consequences, and achieve its intended use in its intended operational environment with the desired level of trustworthiness. [NIST SP 800-160, §3.4.11, Adapted]

Verification: Process of producing objective evidence that sufficiently demonstrates that the system satisfies its security requirements and security characteristics with the level of assurance that applies to the system. [NIST SP 800-160, §3.4.9, Adapted]

Vulnerability: A weakness in an information system, system security procedures, internal controls, or implementation that could be exploited or triggered by a threat source. [NIST SP 800-30]

Wander: The long-term variations—random walk frequency noise—of the significant instants of a digital signal from their ideal position in time (where long-term implies that these variations are of frequency less than 10 Hz). [ITU-T 810, Adapted]

World Geodetic System 1984 (WGS 84): An Earth-centered, Earth-fixed terrestrial reference system and geodetic datum. WGS 84 is based on a consistent set of constants and model parameters that describe the Earth's size, shape, gravity, and geomagnetic fields. WGS 84 is the standard U.S. Department of Defense definition of a global reference system for geospatial information and is the reference system for GPS. It is consistent with the International Terrestrial Reference System (ITRS). [USG FRP]

Appendix C—Additional Resources

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