



December 2022

# GPS DISRUPTIONS

## DOT Could Improve Efforts to Identify Interference Incidents and Strengthen Resilience

Accessible Version

# GAO Highlights

Highlights of [GAO-23-105335](#), a report to the Committee on Transportation and Infrastructure, House of Representatives

## Why GAO Did This Study

GPS provides positioning, navigation, and timing information that enhances transportation safety. Therefore, GPS interference has the potential to significantly harm transportation safety. Federal policy requires DOT to identify and respond to interference incidents in the U.S., improve resilience to GPS interference, and ensure transportation safety.

GAO was asked to review DOT's efforts to identify and address GPS interference effects on transportation safety. This report, among other things: (1) describes interference effects on transportation safety; (2) assesses DOT's processes to identify interference incidents; and (3) assesses DOT's approach to improve resilience to GPS interference.

GAO reviewed federal laws and policies, DOT policies, and analyzed DOT's and other agencies' data on user-reported interference incidents from 2017 through spring 2022. GAO also interviewed federal officials, industry stakeholders, and researchers selected for representation across modes, among other factors.

## What GAO Recommends

GAO is making two recommendations for DOT (1) to document its incident identification process, including identifying controls to obtain complete and accurate information and (2) to develop a strategic approach to resilience that fully aligns with key standards for program management. DOT agreed with these recommendations.

View [GAO-23-105335](#). For more information, contact Heather Krause at (202) 512-2834 or [KrauseH@gao.gov](mailto:KrauseH@gao.gov).

December 2022

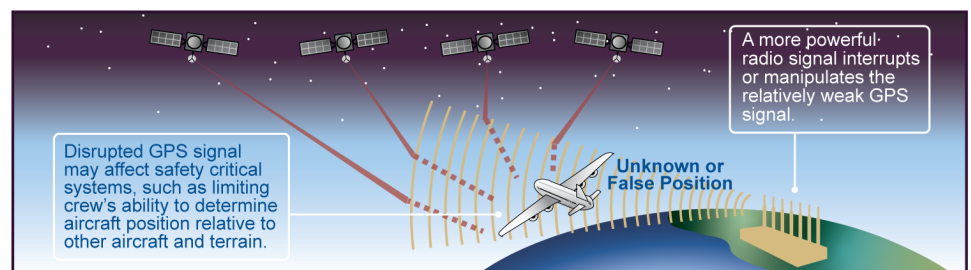
## GPS DISRUPTIONS

### DOT Could Improve Efforts to Identify Interference Incidents and Strengthen Resilience

## What GAO Found

Transportation modes use GPS—a satellite-based system—to obtain positioning, navigation, and timing information. This information enhances transportation safety by supporting surveillance, situational awareness, and emergency response. However, GPS is vulnerable to unintentional and intentional interference from a variety of sources such as solar flares and jamming. Such interference has the potential to affect transportation safety.

#### Example of How Interference with GPS Signals May Affect Aviation Safety



Source: GAO analysis of GPS Interference. | [GAO-23-105335](#)

#### Text of Example of How Interference with GPS Signals May Affect Aviation Safety

- Disrupted GPS signal may affect safety critical systems, such as limiting crew's ability to determine aircraft position relative to other aircraft and terrain.
- A more powerful radio signal interrupts or manipulates the relatively weak GPS signal.

Source: GAO analysis of GPS Interference. | [GAO-23-105335](#)

The Department of Transportation's (DOT) process for identifying potential GPS interference incidents does not result in complete and accurate information. In January 2020, DOT began analyzing user reports of potential GPS interference across all transportation modes to identify incidents and support federal investigations. Through this process, DOT identified 196 potential GPS interference incidents from January 2020 through May 2022. However, GAO found that DOT's process does not include all available user reports, and DOT's data contain inaccurate information. For instance, GAO found that during this period users submitted 72 reports of potential GPS interference to a system DOT does not consider in its process. DOT's process faces limitations because DOT has not documented it nor identified controls to ensure complete and accurate information. Instead, one individual knows how it works, and no other staff review or verify the results. Without a process that produces quality GPS interference information, federal efforts to quickly respond to and stop interference could be delayed.

DOT has undertaken many efforts intended to improve the transportation sector's resilience to GPS interference, such as working to identify potential GPS backups. However, the extent to which DOT's efforts have improved resilience is

unclear because DOT has not taken a strategic approach to guide its efforts. Though DOT has taken steps to plan some of its resilience activities, DOT's current approach does not guide its collective resilience efforts or fully define objectives, prioritize actions, or address challenges, consistent with key program management standards. DOT officials told GAO they are in the process of developing a strategic plan to guide its positioning, navigation, and timing resilience efforts but do not expect the draft to be complete until early 2023. Until DOT has a more strategic approach in place, it is limited in its ability to assess progress toward resilience, leverage limited resources, and navigate long standing challenges to improving resilience.

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### Abbreviations

ASRS	Aviation Safety Reporting System
DHS	Department of Homeland Security
DOD	Department of Defense
DOT	Department of Transportation
E.O. 13905	Executive Order 13905
EXCOM	National Space-Based Positioning, Navigation, and Timing Executive Committee
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
GPS	Global Positioning System
MARAD	Maritime Administration
NASA	National Aeronautics and Space Administration
NAVCEN	U. S. Coast Guard Navigation Center
NSPD-39	National Security Presidential Directive 39
OMB	Office of Management and Budget
OST-R	Office of the Assistant Secretary for Research and Technology
PIRT	Purposeful Interference Response Team
PMI®	Project Management Institute
PNT	positioning, navigation, and timing
PPD-21	Presidential Policy Directive 21
SPD-7	Space Policy Directive 7

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December 15, 2022

The Honorable Peter A. DeFazio  
Chair  
The Honorable Sam Graves  
Ranking Member  
Committee on Transportation and Infrastructure  
House of Representatives

GPS provides positioning, navigation, and timing (PNT) information that enhances transportation safety across all transportation modes. For example, GPS can help aircraft, ships, and vehicles safely navigate in poor weather conditions and high-traffic areas. All transportation modes use GPS extensively to support safe operations. According to one federal estimate, as of 2022, motor vehicles and railroads alone employed tens of millions of GPS units for navigation and other purposes.<sup>1</sup>

However, GPS is vulnerable to interruption or manipulation caused by interference from a variety of sources, such as space weather or intentional jamming. These disruptions have the potential to cause significant harm. For example, one federal study estimated that an extended GPS disruption caused by such an interference incident could cost the U.S. economy \$1 billion per day or more.<sup>2</sup> Federal agencies have long sought to understand, identify, and address interference incidents and improve the resilience of the U.S. transportation system to GPS disruptions (i.e., PNT resilience). The Department of Transportation (DOT) has the lead responsibility for identifying interference incidents affecting civil GPS users in the U.S., among other duties.

You asked us to review the potential impacts of GPS interference on transportation safety and DOT's efforts to identify and address them. This report has three objectives:

1. describes any potential effects of GPS interference incidents on transportation safety that DOT has identified,

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<sup>1</sup> Department of Defense (DOD), Department of Homeland Security (DHS), and Department of Transportation (DOT), *2021 Federal Radionavigation Plan* (2022).

<sup>2</sup> RTI International, *Economic Benefits of the Global Positioning System (GPS)* (June 2019). This report was sponsored by the National Institute of Standards and Technology. The report estimated the impact of a 30-day GPS outage.

2. assesses DOT's processes to identify and respond to GPS interference incidents in the transportation sector as they occur, and
3. assesses DOT's approach to improving the resilience of the transportation sector to future GPS interference incidents.

To address these objectives, we reviewed federal requirements, DOT policies, and interagency agreements and documents governing federal GPS management, including executive orders, memos, and statutes.<sup>3</sup> We interviewed officials and reviewed documents from DOT, some of its operating administrations, and eight other federal agencies and entities that work with DOT to manage GPS, such as the Department of Defense (DOD) and the Department of Homeland Security (DHS).<sup>4</sup> In addition, we selected and interviewed six representatives from the transportation and GPS industries, and seven sets of research stakeholders involved in research or technical standards development (PNT researchers) to obtain their perspectives on interference effects and resilience, among other issues.<sup>5</sup> We selected the industry stakeholders and PNT researchers based on factors such as published work, to obtain perspectives from different transportation modes, and other factors.<sup>6</sup> See appendix I for additional information on the stakeholders we interviewed.

To describe the potential effects of GPS interference on transportation safety that DOT has identified, we reviewed eight studies DOT conducted

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<sup>3</sup> Examples of federal requirements we reviewed include: Exec. Order No. 13905, 85 Fed. Reg. 9,359 (Feb. 18, 2020); Memorandum on Space Policy Directive 7 (SPD-7) (2021); and National Timing Resilience and Security Act of 2018, Pub. L. No. 115-282, § 514, 132 Stat. 4192, 4276-4279 (2018).

<sup>4</sup> For a more complete list of the federal agencies we interviewed, see appendix I.

<sup>5</sup> We refer to these as "sets" of researchers because we held one meeting to interview multiple individuals based on their membership or participation in standards setting or research organizations. The perspective each individual provided was representative of the individual's own views and experiences, and not necessarily the organization of which they are a member. Their perspectives are not generalizable to all such stakeholders and researchers.

<sup>6</sup> We refer to the industry stakeholders and PNT researchers we interviewed collectively as "external stakeholders."



or participated in and used to understand these potential effects.<sup>7</sup> We also asked external stakeholders to corroborate or further describe potential effects that DOT identified.

To assess DOT's processes to identify and respond to GPS interference incidents in the transportation sector, we determined DOT's process to obtain and analyze user-reported data to identify interference incidents by interviewing relevant DOT officials and external stakeholders. We also analyzed DOT's Office of the Assistant Secretary for Research and Technology's (OST-R) consolidated GPS anomaly data, among other federal data such as interference reports users submitted to the U.S. Coast Guard Navigation Center (NAVCEN). We sought to obtain data from 2017 to the most current data available.<sup>8</sup> We assessed the reliability of these data and found them to have some limitations. But we determined that they were reliable for our purposes of describing the number and type of reports users submitted by reviewing agency documentation, among other steps. We will discuss the limitations associated with these data later in this report. We compared this information to DOT's responsibilities outlined in federal policy and to federal internal control standards to evaluate the extent to which DOT's process was documented and resulted in quality information.<sup>9</sup> Additionally, we reviewed DOT and interagency documentation and interviewed officials to understand how DOT and its operating administrations respond to the GPS interference incidents DOT identifies.

To assess DOT's approach to improving the resilience of the transportation sector to GPS interference, we reviewed documentation of

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<sup>7</sup> While there is a substantial amount of research and literature available on GPS interference and its effects, our objective was to describe the potential effects of GPS interference that DOT has identified. As a result, we reviewed studies that DOT conducted or contributed to and that DOT officials told us DOT used to inform its understanding of potential interference effects.

<sup>8</sup> DOT was able to provide data from January 2020 through May 2022 because it started analyzing the data in January 2020. We reviewed user reports submitted to NAVCEN from January 2017 through January 2022, and user reports submitted to NASA's Aviation Safety Reporting System (ASRS) from January 2017 through December 2021.

<sup>9</sup> SPD-7 (2021): Sec. 7. (d)(viii). DOT is required to monitor, identify, locate, and attribute GPS disruptions in the U.S. that adversely affect transportation safety. We evaluated DOT's processes to identify (related to monitoring and identifying) incidents separately from its processes to respond (related to locating and attributing) because DOT has different procedures for these respective steps and because DOT's procedures represent different steps in a sequential process. GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: Sep. 2014).

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DOT's actions to improve PNT resilience in the transportation sector.<sup>10</sup> We also interviewed DOT officials about DOT's approach to improving PNT resilience.<sup>11</sup> Because DOT has identified its PNT activities as a distinct program, we reviewed the Office of Management and Budget's (OMB) federal strategic planning guidance, and corresponding standards for a strategic approach to program management from the Project Management Institute (PMI®).<sup>12</sup> We assessed documents that DOT officials told us comprise the agency's current approach to PNT resilience against key PMI® standards.<sup>13</sup> Additionally, we reviewed federal reports and obtained the perspectives of agency officials and external stakeholders on challenges to improving PNT resilience. See appendix II for information on these challenges. For complete information on our objectives, scope, and methodology, see appendix I.

We conducted this performance audit from July 2021 to December 2022 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain

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<sup>10</sup> We reviewed actions DOT took related to federal requirements generally covering the period of fiscal year 2017 through 2022.

<sup>11</sup> Because we could not identify a single federal definition for PNT resilience, we developed a definition based on the following documents: White House, *Critical Infrastructure Security and Resilience*, Presidential Policy Directive/PPD-21 (Feb. 12, 2013); DHS, *Resilient PNT Conformance Framework* (Apr. 26, 2022); and National Science and Technology Council, *National Research and Development Plan for PNT Resilience* (August 2021). We then identified the federal laws and policies that require DOT to take actions intended to improve PNT resilience in the transportation sector based on our definition and associated criteria, and confirmed our assessment with DOT officials.

<sup>12</sup> OMB, *Improving the Management of Federal Programs and Projects through Implementing the Program Management Improvement Accountability Act*, M-18-19 (Washington, D.C.: June 25, 2018). Project Management Institute, Inc. (PMI®), *The Standard for Program Management*, Fourth Edition (2017). PMI® is a registered mark of the Project Management Institute, Inc. In December 2019, GAO reported that agencies could benefit from more detailed standards than those in M-18-19, and that OMB's standards and principles are similar to PMI's® program management standards. GAO, *Improving Program Management: Key Actions Taken, but Further Efforts Needed to Strengthen Standards, Expand Reviews, and Address High-Risk Areas*, [GAO-20-44](#) (Washington, D.C.: Dec. 13, 2019). We identified the PMI® program management standards that are consistent with, but elaborate on, the strategic planning standards in OMB M-18-19. Since the standards we selected are key for a strategic approach to program management, we refer to these standards as "key standards" for a strategic approach to program management.

<sup>13</sup> For example, we assessed DOT's research and development implementation document and budget documents, among others. DOT, *DOT Implementation Activities Supporting the National Research and Development Plan for Positioning, Navigation & Timing (PNT) Resilience* (August 2022).

sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

## Background

### GPS and Interference

GPS is a satellite-based system developed and operated by DOD that provides PNT information to transportation owners and operators for a variety of uses, including to enhance safety.<sup>14</sup> To improve safety, transportation modes use GPS for navigation, surveillance, situational awareness, and emergency response. Table 1 describes examples of how different transportation modes may use GPS to improve safety.

**Table 1: Examples of How Transportation Modes Use GPS to Improve Safety**

Use	Examples from transportation modes
Navigation: <i>facilitating safe point-to-point travel</i>	<ul style="list-style-type: none"><li>• Aircraft use GPS in all phases of flight to determine aircraft position and timing to support safe navigation, especially in limited visibility conditions.</li><li>• Marine vessels use GPS position data to safely navigate in high-traffic, high-risk areas, such as inland rivers, canals, and ports.</li><li>• Automobiles, delivery vans, and heavy trucks use GPS navigation information to support mapping and routing services that allow vehicles to, for example, avoid traffic.</li></ul>
Surveillance: <i>determining location relative to other vehicles</i>	<ul style="list-style-type: none"><li>• Aircraft use GPS to determine their positions, which they then broadcast to other aircraft and air traffic control. GPS-based surveillance is a critical element of federal efforts to modernize the air traffic control system, known as the Next Generation Air Transportation System.</li><li>• Vessels use GPS to determine their position and timing, which they broadcast to nearby vessels and shoreside networks.</li><li>• Railroads will use GPS position and timing information from future vehicle-to-infrastructure technology to alert train operators to the risk of collision with road vehicles at grade crossings.<sup>a</sup></li><li>• Automated driving systems and intelligent transportation systems will use GPS to determine vehicle's position, which vehicles may communicate to each other and to roadway infrastructure.<sup>a</sup></li></ul>

<sup>14</sup> While DOD operates GPS, GPS is freely available to all users on a continuous, worldwide basis.

Use	Examples from transportation modes
Situational Awareness: <i>identifying environmental hazards</i>	<ul style="list-style-type: none"> <li>• Aviation systems that alert flight crews to potentially hazardous conditions, such as dangerous terrain, use GPS for position (e.g. altitude) and timing.</li> <li>• Waterway and vessel systems use GPS to determine a vessel's position in relation to environmental hazards, such as shallow water.</li> <li>• Positive train control systems use GPS position and timing information to automatically slow or stop a train when it is going too fast for conditions to prevent over-speed derailments, among other things.</li> <li>• Truck-specific navigation systems use GPS position data to provide critical roadway information to commercial vehicle operators, such as bridge clearance restrictions.</li> </ul>
Emergency Response: <i>supporting rapid search and rescue efforts</i>	<ul style="list-style-type: none"> <li>• GPS position information improves the quality of information transmitted by emergency locators when aircraft are in distress.</li> <li>• GPS position and timing information is integrated into signals from vessels in distress, which speeds emergency response.</li> <li>• Some vehicles are equipped with onboard systems that detect crashes and automatically transmit GPS position and time data to emergency medical services.</li> </ul>

Source: GAO analysis of Department of Transportation information. | GAO-23-105335

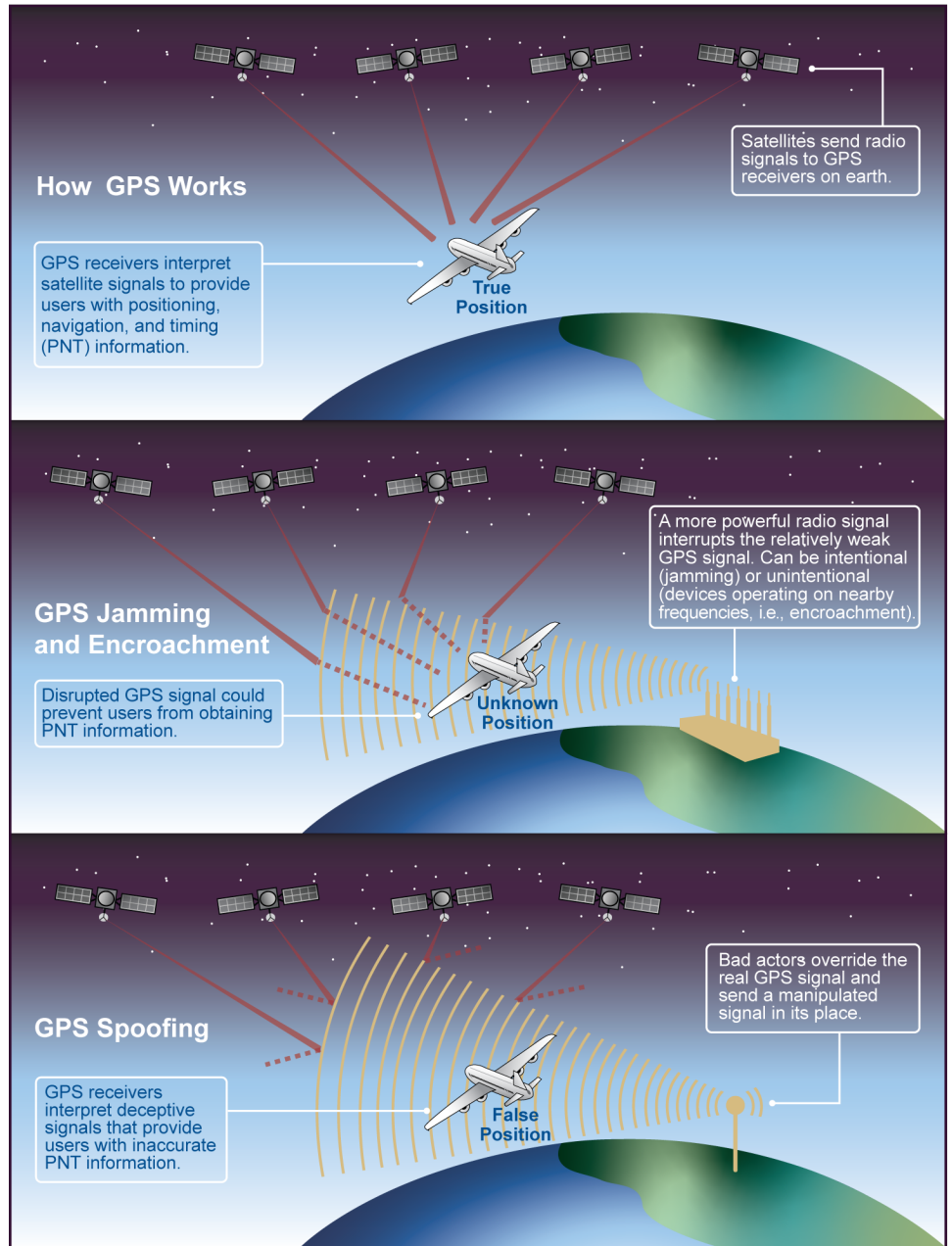
Note: GPS provides position, navigation, and timing information. Position information comprises the precise physical location of the aircraft, vessel, vehicle, or railcar. Navigation information comprises efficient travel routes between two or more known physical positions. Timing information comprises a precise timestamp for use by an individual device and systems. Taken together, timing and position information can, for example, be used to calculate velocity and rate of speed. Some transportation modes and applications may also use systems that augment GPS to obtain additional precision, integrity, and availability of positioning, navigation, and timing information under certain operation conditions.

<sup>a</sup>These technologies are in development.

GPS is susceptible to interference, which occurs when the GPS signal is interrupted or manipulated as it is transmitted from GPS satellites to users' equipment. This results in lost or inaccurate PNT information. GPS interference can be unintentional, for example when devices operating on nearby frequencies (which we refer to as encroachment) or naturally occurring space weather interrupt GPS signals. However, bad actors can also intentionally interfere with GPS through "jamming" and "spoofing."<sup>15</sup> Figure 1 describes how different kinds of interference may occur.

<sup>15</sup> Willful and malicious interference with GPS signals, including jamming and spoofing GPS signals, is prohibited under 47 U.S.C. § 333. See, also, 47 U.S.C. § 302a(b) and 47 U.S.C. § 301. A jammer emits signals that block or degrade the GPS signal, while a spoofer replaces the GPS signal with a manipulated signal that may provide incorrect PNT information.

Figure 1: Example of Interference with GPS Signals in Aviation



Source: GAO analysis of GPS Interference. | GAO-23-105335

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**Text of Figure 1: Example of Interference with GPS Signals in Aviation**

**How GPS Works**

- GPS receivers interpret satellite signals to provide users with positioning, navigation, and timing (PNT) information.
- Satellites send radio signals to GPS receivers on earth.

**GPS Jamming and Encroachment**

- Disrupted GPS signal could prevent users from obtaining PNT information.
- A more powerful radio signal interrupts the relatively weak GPS signal. Can be intentional (jamming) or unintentional (devices operating on nearby frequencies, i.e., encroachment).

**GPS Spoofing**

- GPS receivers interpret deceptive signals that provide users with inaccurate PNT information.
- Bad actors override the real GPS signal and send a manipulated signal in its place.

Source: GAO analysis of GPS Interference. | GAO-23-105335

Note: GPS interference affects other transportation modes' use of GPS, including surface and maritime modes, similarly.

DOD may also intentionally interfere with GPS signals in select locations for military training and testing purposes, referred to as planned interference.<sup>16</sup> DOD coordinates interference testing with FAA, on behalf of DOT, and other federal agencies to minimize effects on civil aviation and maritime operations.<sup>17</sup>

Federal agencies rely on GPS users' reports to identify when GPS interference is occurring. Pilots and other civil aviation users can report suspected GPS interference to FAA. Other civil transportation users (e.g., mariners, drivers, and train operators) can report to the Coast Guard's NAVCEN. Users typically provide a subjective narrative of the incident, including any effects on their operations or safety, among other

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<sup>16</sup> DOD is responsible for training and testing U.S. military forces in operationally realistic conditions that include denial or degradation of GPS.

<sup>17</sup> Chairman of the Joint Chiefs of Staff Manual, *Performing Tests, Training, and Exercises Impacting the Global Positioning System (GPS)*, CJCSM 3212.03A (Nov. 8, 2013).

information. Although these user reports do not represent all GPS interference that occurs in the U.S., DOT officials have stated that they are, and will continue to be, a critical tool for the federal government to identify, document, and assess GPS interference incidents affecting transportation safety.<sup>18</sup>

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## Resilience

Because the transportation sector has broadly adopted GPS, resilience to disruptions caused by GPS interference is essential to maintain transportation safety. For the purposes of our review, we define “PNT resilience” as the ability of PNT systems to withstand and recover from GPS interference from any source without harmfully degrading or losing PNT information.<sup>19</sup> DOT and other federal agencies have reported that, among other steps, having (1) a GPS backup or complementary PNT capability<sup>20</sup> and (2) equipment that resists or detects interference improves resilience.

Improving resilience to GPS disruption has long been a federal priority. However, federal and private sector stakeholders face a number of long-standing, well-known challenges to improving PNT resilience. For example, in 2013 we reported that DOT and DHS faced challenges establishing GPS backups and complementary PNT capabilities. As a result, we recommended that the agencies improve coordination to

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<sup>18</sup> User reports do not indicate how often GPS interference occurs in the U.S., because GPS users do not always report interference for a variety of reasons. For example, users may not be aware that interference is occurring. DHS, *National Risk Estimate* (2012). DOT has efforts underway to more completely detect interference with civil GPS signals. DOT requested and received funding in fiscal year 2022 for these efforts.

<sup>19</sup> Our definition reflects a fully resilient system, but DOT officials noted that the transportation sector has many diverse PNT applications, and not all of them may require this level of resilience. According to DHS, a resilient PNT system can continue to provide PNT information during disruptions (withstand) and return to typical performance after attacks or disruptions have affected the system (recover). Department of Homeland Security Science and Technology Directorate, *Resilient Positioning, Navigation, and Timing (PNT) Reference Architecture* (2022). DOT officials also stated that DOT agrees with the DHS Resilient PNT Conformance Framework, which defines four levels of resiliency. DHS, *Resilient PNT Conformance Framework* (Apr. 26, 2022).

<sup>20</sup> A GPS backup capability provides PNT information in the event of a GPS disruption at equal or lesser performance in terms of accuracy, availability, and coverage. A complementary PNT capability may provide PNT information in environments where GPS performance typically is limited (e.g., indoors, underground, etc.). Volpe Center, *Complementary PNT and GPS Backup Technologies Demonstration Report* (January 2021).

develop a GPS backup, but they did not implement our recommendation.<sup>21</sup> Similarly, in 2022, we reported that DOD faced challenges identifying PNT alternatives, and recommended that DOD identify strategic objectives and metrics for its efforts. This recommendation has not yet been implemented.<sup>22</sup> Stakeholders we spoke to also identified several challenges. See appendix II for more information.

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## Federal GPS Policy and Responsibilities

For nearly two decades, the executive branch of the U.S. government has emphasized a “whole-of-government” approach to manage GPS and address interference. This approach is outlined in a variety of policies and directives, including:

- Memorandum on Space Policy Directive 7 (SPD-7) seeks to protect GPS from harmful interference, invest in capabilities to detect and mitigate GPS interference, and promote PNT resilience, among other activities.<sup>23</sup>

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<sup>21</sup> GAO, *GPS Disruptions: Efforts to Assess Risks to Critical Infrastructure and Coordinate Agency Actions Should be Enhanced*, [GAO-14-15](#) (Washington, D.C.: Nov. 6, 2013). We recommended, among other things, that DOT and DHS establish a formal, written agreement that details how the agencies plan to address their shared responsibility for establishing a GPS backup. The agencies did not do so, and we closed the recommendation as not implemented in 2020. National Security Presidential Directive 39 (NSPD-39) required DOT and DHS to establish a GPS backup, but this policy was superseded by new federal policy in 2021. The National Defense Authorization Act for Fiscal Year 2017 included continued requirements for DOT and DHS to identify and plan for GPS backups. Pub. L. No. 114-328, § 1618, 130 Stat. 2000, 2595-2596 (2016). DHS officials told us that the National Timing Resilience and Security Act of 2018 required DOT to establish a backup timing system for GPS without reference to DHS, and in their view, complicated coordination and roles DHS has in this area.

<sup>22</sup> GAO, *GPS Alternatives: DOD is Developing Navigation Systems But Is Not Measuring Overall Progress*, [GAO-22-106010](#) (Washington, D.C.: Aug. 5, 2022). We recommended, among other things, that DOD should create strategic objectives and metrics to measure progress toward DOD’s alternative PNT efforts. DOD concurred with this recommendation.

<sup>23</sup> SPD-7 (2021). SPD-7 superseded NSPD-39 which was issued in 2004 and previously identified policy priorities and roles and responsibilities for federal GPS management. However, SPD-7 maintained many similar roles and responsibilities and policy priorities.



- Executive Order 13905 (E.O. 13905) directs federal agencies to engage the public and private sectors to improve the PNT resilience of critical infrastructure sectors.<sup>24</sup>
- Presidential Policy Directive on Critical Infrastructure Security and Resilience (PPD-21) aims to enhance federal coordination to improve critical infrastructure and resilience, which includes protection from GPS interference.<sup>25</sup>

Federal laws and policy also designate roles and responsibilities for managing GPS. DOT's responsibilities include:

- ensuring safe and efficient transportation;<sup>26</sup>
- serving as the lead civilian agency on GPS-related issues;<sup>27</sup>
- monitoring, identifying, locating, and attributing GPS disruptions in the U.S. that adversely affect transportation safety. (For our purposes, monitoring and identifying refers to efforts to identify when GPS interference affecting users is occurring, and locating and attributing refers to efforts to respond to the interference by taking steps to determine the source.); and<sup>28</sup>

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<sup>24</sup> Exec. Order No. 13905, 85 Fed. Reg. 9359, (Feb. 18, 2020). E.O. 13905 refers to PNT resilience as the responsible use of PNT services.

<sup>25</sup> PPD-21 (Feb. 12, 2013).

<sup>26</sup> 49 U.S.C. § 101.

<sup>27</sup> SPD-7 (2021).

<sup>28</sup> SPD-7 requires that DOT fulfill this responsibility in coordination with DOD and DHS. In addition to disruptions that are affecting transportation, DOT must identify disruptions affecting any civil users in the U.S. According to agency officials, DOT has general authority to conduct certain analyses and tests to investigate and assess certain interference incidents, including GPS interference incidents impacting transportation. When DOT determines or suspects that the source is a non-federal system, DOT may seek voluntary cooperation. However, if an entity declines to cooperate, DOT must coordinate with FCC. DOT officials explained that FCC has regulatory oversight authority of non-government sources of interference and that DOT does not have authority on its own to enforce compliance regarding these GPS interference incidents. As such, according to DOT officials, DOT accomplishes this mission jointly with FCC. DOT officials further explained that its investigatory authority is more constrained in dealing with suspected purposeful GPS interference in certain contexts. DOT, in addressing its SPD-7 responsibilities, and other civil space agencies must report their assessment of suspected purposeful interference to the appropriate members of the purposeful interference response team (PIRT) for further investigation and enforcement.

- leading and supporting efforts to improve PNT resilience in the transportation sector and protect GPS from harmful interference.<sup>29</sup>

Within DOT, OST-R oversees the department's PNT activities and is responsible for coordinating PNT planning internally and with other civil federal agencies and organizations. Among DOT's operating administrations, FAA has specific responsibilities for PNT management, such as receiving reports of GPS interference from civilian aviation users.<sup>30</sup> Other operating administrations may engage with OST-R to manage PNT, and report, document, or address GPS interference and resilience in their respective modes.

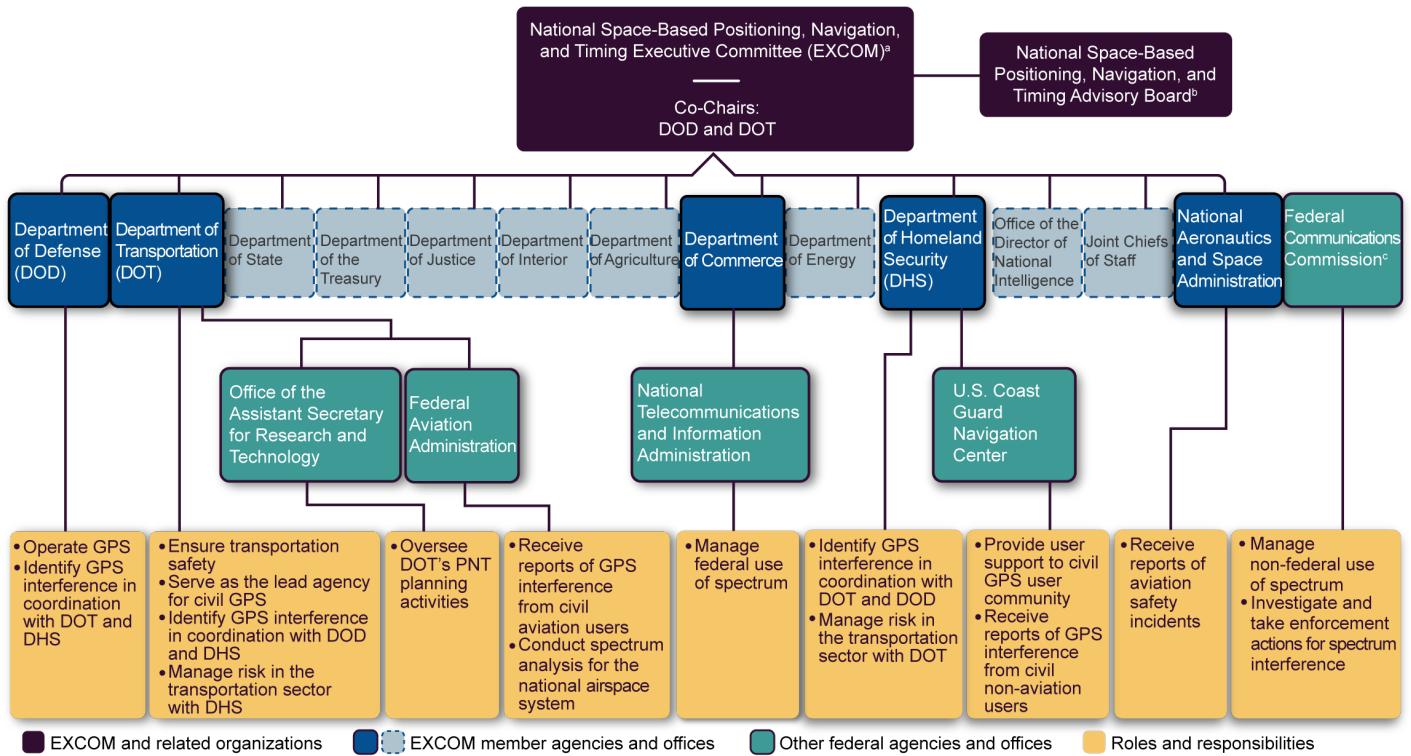
Multiple federal agencies and interagency organizations have responsibilities to work with DOT to identify, respond, and improve resilience to GPS interference in the transportation sector (see figure 2).

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<sup>29</sup> These responsibilities are outlined in E.O. 13905, SPD-7, and PPD-21.

<sup>30</sup> 49 U.S.C. § 44505. FAA is also responsible for developing and implementing PNT systems to meet the needs for safe and efficient air navigation, such as the Wide Area Augmentation System, a system that enhances GPS to provide precise PNT information required for aviation.

**Figure 2: Organization of Federal Roles and Responsibilities for Managing Space-Based Positioning, Navigation, and Timing (PNT) in the Transportation Sector**



Source: GAO analysis of EXCOM and DOT information. | GAO-23-105335

**Text of Figure 2: Organization of Federal Roles and Responsibilities for Managing Space-Based Positioning, Navigation, and Timing (PNT) in the Transportation Sector**

**Department of Defense (DOD)**

- Operate GPS
- Identify GPS interference in coordination with DOT and DHS

**Department of Transportation (DOT)**

- Ensure transportation safety
- Serve as the lead agency for civil GPS
- Identify GPS interference in coordination with DOD and DHS
- Manage risk in the transportation sector with DHS

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**Department of Transportation (DOT): Office of the Assistant Secretary for Research and Technology**

- Oversee DOT's PNT planning activities

**Department of Transportation (DOT): Federal Aviation Administration**

- Conduct spectrum analysis for the national airspace system
- Receive reports of GPS interference from civil aviation users

**Department of Commerce: National Telecommunications and Information Administration**

- Manage federal use of spectrum

**Department of Homeland Security (DHS)**

- Identify GPS interference in coordination with DOT and DOD
- Manage risk in the transportation sector with DOT

**Department of Homeland Security (DHS): U.S. Coast Guard Navigation Center**

- Provide user support to civil GPS user community
- Receive reports of GPS interference from civil non-aviation users

**National Aeronautics and Space Administration**

- Receive reports of aviation safety incidents

**Federal Communications Commission/c/**

- Manage non-federal use of spectrum
- Investigate and take enforcement actions for spectrum interference

Source: GAO analysis of EXCOM and DOT information. | GAO-23-105335

Notes: The agencies and offices that are in bold outline have a role in supporting DOT's efforts to identify, respond to, and improve resilience to GPS interference incidents affecting the U.S. transportation system. The agencies in dashed outline are other agencies involved in overall federal PNT management.

<sup>a</sup>The EXCOM is an interagency body that coordinates GPS related matters across 13 federal agencies. The National Coordination Office supports the operations of the EXCOM.

<sup>b</sup>The PNT Advisory Board is an independent board comprised of GPS experts outside the U.S. government that advises the EXCOM.

<sup>c</sup>The Federal Communications Commission (FCC) is not a member of the EXCOM but can be invited by the EXCOM co-chair to participate in meetings in an advisory role. FCC may take enforcement

actions for interference by non-government entities. FCC establishes rules regarding harmful interference to users of non-federal spectrum. FCC works in coordination with the National Telecommunications and Information Administration, which manages federal use of spectrum.

In addition to federal agencies, private sector owners and operators are responsible for identifying and reporting GPS interference to the federal government and improving PNT resilience to manage risk to their operations. The private sector also has a role in developing and manufacturing GPS user equipment, as well as developing and providing complementary PNT services, such as devices that can use cellular networks to provide PNT information in the event of a GPS disruption.

## DOT Has Identified and Continues to Study Potential Safety Effects of GPS Interference across Modes

DOT has identified multiple potential safety effects of GPS interference across all transportation modes. According to DOT studies we reviewed, GPS interference could affect transportation safety in different ways. See table 2.

**Table 2: Potential Effects of GPS Interference on Transportation Safety**

Transportation Mode	Potential Safety Effects
Aviation	<ul style="list-style-type: none"> <li>• Reduced performance of aircraft systems that ensure safe flight, such as systems designed to stabilize aircraft movements and warn pilots of dangerous terrain.</li> <li>• Reduced situational awareness caused by degraded surveillance and monitoring capabilities, resulting in safety risks such as incorrect separation between aircraft.</li> <li>• Increased flight crew and air traffic controller workload and confusion, which increase risks to other safety-critical operations.</li> </ul>
Maritime	<ul style="list-style-type: none"> <li>• Reduced performance of vessel systems that ensure safe navigation, such as collision avoidance systems, reducing situational awareness and increasing the risk of collision.</li> <li>• Reduced situational awareness can increase risk of grounding—a particular safety risk for vessels carrying hazardous materials.</li> </ul>
Rail	<ul style="list-style-type: none"> <li>• Reduced performance of positive train control systems—automated systems designed to slow or stop a train when it is not operating safely—increasing the probability of train accidents.</li> <li>• Disrupted right-of-way controls at rail-highway interfaces increase risk of train-vehicle collisions.</li> </ul>
Highway	<ul style="list-style-type: none"> <li>• Disrupted remote traffic control systems or right-of-way controls at rail-highway interfaces increase risk of vehicle-vehicle or train-vehicle collisions.</li> </ul>

Source: GAO analysis of studies conducted or contributed to and used by the Department of Transportation. | GAO-23-105335

Federal and external stakeholders we spoke to identified similar potential effects. For example, three different sets of PNT researchers we spoke to explained that GPS interference could affect maritime vessels' ability to avoid collisions. One set of researchers pointed to a 2017 incident in the

Black Sea in which dozens of vessels nearly collided when their GPS signals were spoofed.

Based on DOT studies and our interviews with external stakeholders, we identified three factors that can influence the extent to which interference ultimately affects transportation safety: (1) the mode of transportation, (2) operational factors, and (3) the availability of complementary PNT systems.

**Transportation mode.** GPS interference may affect safety in some modes more than others. DOT studies we reviewed and external stakeholders we spoke to overwhelmingly identified potential safety effects in aviation relative to the maritime and surface transportation modes. The inherent risk of the transportation mode and its dependence on GPS may contribute to this variation. For instance, one DOT official pointed out that a pilot cannot pull an aircraft over to the side of the road until GPS signal is recovered like the driver of a car or truck.

Though DOT studies and external stakeholders generally identified fewer effects in the surface modes, DOT officials told us that these modes are vulnerable. DOT officials told us that DOT has received at least two incident reports from drivers whose navigation systems directed them into oncoming traffic. Officials noted that drivers often trust such GPS instructions and follow them without question; this trust has led to a number of accidents and demonstrates how interference could affect safety in modes generally thought to be less susceptible. For example, in July 2022, a driver followed their GPS into the Pascagoula River in Mississippi and nearly drowned.<sup>31</sup>

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<sup>31</sup> Lindsey Bever, "As car sank, teen saved 3 girls and a police officer in river rescue," *Washington Post*, July 7, 2022. This incident appeared to be caused by a GPS error and not GPS interference but demonstrates how reliance on GPS could influence safety in the event of GPS interference.

**Operational factors.** Nearly all of the studies we reviewed (7 of 8) and most of the external stakeholders we spoke to (9 of 13) told us that operational factors such as bad weather, dangerous terrain, specific phases of travel, or interdependencies between GPS and other operating systems can make GPS interference more dangerous.<sup>32</sup> For example, GPS interference may have more of an effect on safety if it occurs during the takeoff or landing phases of flight when an aircraft is closer to the ground. Additionally, a couple of DOT studies and an industry stakeholder told us that interference can affect aircraft systems that alert pilots to dangerous terrain, which could result in incorrect or missed alerts. See the sidebar for an example of how one flight was affected by interdependencies between GPS and other systems.

**Complementary PNT systems.** The availability of complementary PNT systems can mitigate some safety effects of GPS interference. All but one DOT study we reviewed found that in most circumstances, transportation operations across modes can continue safely when GPS is disrupted if complementary PNT systems or operating procedures are available to the user. More than half of these studies (5 of 8) found that operators may generally revert back to the navigation methods employed before GPS was used to maintain safety. For instance, one study found that complementary systems such as legacy ground-based navigation aids and air traffic management procedures would allow aircraft to continue to operate safely.<sup>33</sup>

These three factors may also interact with each other to influence the effect GPS interference has on safety. For example, one general aviation stakeholder told us that general aviation aircraft are more likely to have a

**How System Interdependencies Affected One Aircraft During a GPS Disruption**

According to a safety message issued by the Federal Aviation Administration (FAA), in April 2016, a small private jet encountered GPS interference and lost all GPS signals. Due to unforeseen dependencies between the GPS receiver and other aircraft systems, the system that helps stabilize the aircraft malfunctioned. As a result, the aircraft entered a Dutch Roll, a movement similar to fishtailing with the addition of a rocking motion, which can be dangerous if not properly controlled. The aircraft made an emergency descent.

Source: FAA. | GAO-23-105335

<sup>32</sup> DHS officials we spoke with explained that interdependencies between GPS and other systems can make interference more dangerous only if they are improperly engineered and if the system design does not take into account the potential for GPS anomalies.

<sup>33</sup> DOD, DHS, DOT, *2021 Federal Radionavigation Plan* (2022).

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**Effects of a GPS Spoofing Experiment on a Partially Automated Vehicle**

In June 2019 a cybersecurity company successfully spoofed the GPS-based navigation system of a partially automated vehicle in a live experiment. Using a mimicked GPS signal, the researchers directed the vehicle to turn into oncoming traffic on a two-lane road. Researchers noted that the driver was able to manually correct the maneuver, but warned that distracted or unaware drivers may not react in time to prevent an accident.

Source: GPS World. | GAO-23-105335

single pilot, fly at lower altitudes and over dangerous terrain, and are equipped with fewer complementary PNT technologies than commercial aircraft. As a result, this stakeholder told us that general aviation aircraft could experience more safety effects from GPS interference relative to commercial aircraft.

While DOT has identified the potential effects of GPS interference on existing transportation technologies, DOT is also working to understand how GPS interference could affect new and emerging intelligent transportation technologies. DOT supports research on the effects of GPS interference on automated vehicles and intelligent transportation systems, which could be significant (see sidebar).<sup>34</sup> For example, one set of PNT researchers explained that interference with GPS signals used by traffic lights or vehicles in connected vehicle systems could cause crashes. Additionally, DOT continues to study the effects of interference caused by potential encroachment from new telecommunications infrastructure which it found could pose a threat to transportation safety, especially to helicopter operations.<sup>35</sup>

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## DOT Does Not Have a Documented Process to Completely and Accurately Identify GPS

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<sup>34</sup> DOT officials told us that DOT supports research on future automated vehicle and intelligent transportation system technologies through its University Transportation Center, the Highly Automated Systems Safety Center of Excellence, and its Intelligent Transportation System Joint Program Office. For instance, in 2020, DOT awarded almost \$2 million to establish the University Transportation Center for Automated Vehicles Research with Multimodal Assured Navigation (CARMEN), which studies the vulnerabilities of highly automated transportation systems to PNT interference and disruptions and resilient PNT solutions.

<sup>35</sup> DOT, *Global Positioning System (GPS) Adjacent Band Compatibility Assessment* (April 2018).



## Interference Incidents but Has Formal Response Processes

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### DOT Identifies Interference Incidents Using an Informal Process That Does Not Produce Quality Information

DOT is required to identify GPS interference incidents adversely affecting transportation users in the U.S.<sup>36</sup> DOT officials told us that in January 2020, DOT began centralizing and assessing reports of potential interference that GPS users submit to FAA and NAVCEN to identify interference incidents across modes.<sup>37</sup> DOT officials told us that DOT has not documented its process. As a result, figure 3 depicts the incident identification process DOT officials described to us. According to DOT officials, the agency analyzes user reports to determine if federal investigation and response is needed. Officials also explained that this user-based process does not identify all interference that occurs in the U.S because users do not always report interference.<sup>38</sup> Rather, they said that DOT's process identifies user-reported potential interference incidents affecting transportation safety and then determines whether these incidents were caused by interference.

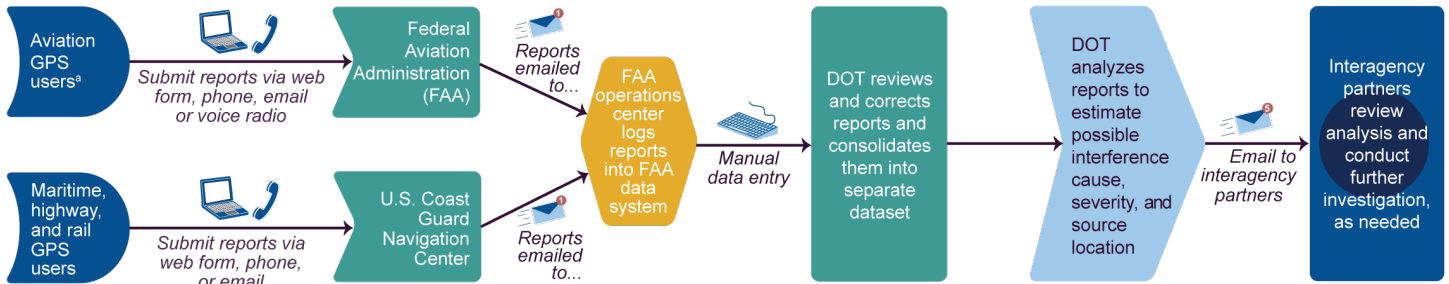
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<sup>36</sup> SPD-7 (2021). This directive includes a requirement for DOT to monitor, identify, locate and attribute GPS disruptions in the U.S. that adversely affect users. We consider DOT's efforts to identify GPS interference incidents to be related to the parts of the requirement related to monitoring and identifying GPS disruptions. We discuss DOT's efforts to respond—which correspond with the parts of the requirement to locate and attribute disruptions, separately.

<sup>37</sup> DOT officials told us that prior to January 2020, FAA only reviewed reports of possible GPS interference from aviation users. However, DOT did not review reports across all modes. As a result, in January 2020 DOT began centralizing reports submitted from GPS users in all modes. DOT officials told us that a small number of reports may also come to DOT through other means, such as directly from other agencies or from users through phone or email reports.

<sup>38</sup> As of 2022, the federal government relies on reports from GPS users to identify when interference occurs in the U.S. because no automated interference detection system exists. Federal and external stakeholders we spoke with told us that user reports are not representative of the total number of interference incidents that actually occur in the U.S. because users may not always report incidents for a variety of reasons. For example, users may not know if they experienced interference or the interference did not cause a problem. DOT requested and received funding in fiscal year 2022 to develop a sensor-based automated interference detection system that it anticipates will be able to detect when GPS signals are disrupted across the U.S. When this system is completed, DOT stated that it will continue to use user reports to identify when such disruptions are causing harm and match those reports with the results of the automated detection system.

**Figure 3: Department of Transportation’s (DOT) Process to Identify GPS Interference Incidents Affecting Users in the U.S.**



Source: GAO analysis of interviews with DOT officials. | GAO-23-105335

**Text of Figure 3: Department of Transportation’s (DOT) Process to Identify GPS Interference Incidents Affecting Users in the U.S.**

1. **Aviation GPS users /a/**
  2. Submit reports via web form, phone, email or voice radio to
  3. Federal Aviation Administration (FAA), reports emailed to
  4. FAA operations center logs reports into FAA data system, manual data entry and
  5. DOT reviews and corrects reports and consolidates them into separate dataset
  6. DOT analyzes reports to estimate possible interference cause, severity, and source location, email to interagency partners
  7. Interagency partners review analysis and conduct further investigation, as needed
1. **Maritime, highway, and rail GPS users**
  2. Submit reports via web form, phone, email or voice radio to
  3. U.S. Coast Guard Navigation Center, reports emailed to
  4. FAA operations center logs reports into FAA data system, manual data entry and
  5. DOT reviews and corrects reports and consolidates them into separate dataset
  6. DOT analyzes reports to estimate possible interference cause, severity, and source location, email to interagency partners
  7. Interagency partners review analysis and conduct further investigation, as needed

Source: GAO analysis of interviews with DOT officials. | GAO-23-105335

Notes: DOT may also receive user reports from other federal or state agencies, such as the Department of Homeland Security, which may become aware of an incident through its oversight of critical infrastructure. According to DOT officials, DOT may also receive a small number of reports from users via phone or email. DOT officials told us that this process is intended to identify interference incidents that users report are affecting transportation safety and is not intended to identify all interference that occurs in the U.S. FAA uses its Remote Monitoring and Logging System, a system of record for information about the National Airspace System, to log user reports of GPS interference.

<sup>a</sup>Aviation users may include any user of the national airspace system, including air traffic controllers.

We found that DOT identified 196 potential interference incidents from January 2020 through May 2022 through this process (see table 3).

**Table 3: Number of Potential GPS Interference Incidents Reported by U.S. Civil Users and Identified by the Department of Transportation (DOT) by Reporting Source, January 2020 through May 2022**

Source	2020	2021	2022	Total
Federal Aviation Administration web form	46	57	13	116
U.S. Coast Guard Navigation Center web form	29	23	9	61
Air Traffic Control	5	2	3	10
Air Safety Action Programs <sup>a</sup>	0	1	0	1
Other <sup>b</sup>	4	3	1	8
<b>Total</b>	<b>84</b>	<b>86</b>	<b>26</b>	<b>196</b>

Source: GAO analysis of DOT Data. | GAO-23-105335

Notes: These data include some reports from non-transportation users, such as land surveyors, because any GPS user may submit a report via the web forms. These figures represent the number of potential incidents that DOT identified through user reports, not the total number of reports GPS users submitted to the federal government or the total number of actual interference incidents that occurred in the U.S.

<sup>a</sup>This category includes the Aviation Safety Action Program and the Air Traffic Safety Action Program. These programs are anonymous safety reporting systems for pilots and air traffic controllers that seek to enhance aviation safety through the prevention of accidents and incidents.

<sup>b</sup>The “other” category includes, for example, reports of incidents provided to DOT by other agencies or through other means.

However, we found that DOT’s process does not completely and accurately identify user-reported potential interference incidents due to several limitations. Because DOT has not documented its process, it is limited in its ability to address these limitations. Specifically:

**Incomplete user reports.** DOT’s process to identify incidents does not include some sources that may contain relevant user reports of potential interference incidents. We identified three sources for user reports of potential interference that DOT does not routinely consider in its process. Without documenting its process, DOT cannot determine how to consider these or other sources of information that DOT needs to ensure it is identifying incidents using the most complete information possible.

*Aviation Safety Action Program and Air Traffic Safety Action Program.* Pilots and air traffic controllers we spoke to told us that

they report suspected GPS interference incidents through FAA's Aviation Safety Action Programs and the Air Traffic Safety Action Program respectively.<sup>39</sup> Though DOT officials told us that pilots and air traffic controllers may report interference to these programs, we found that DOT considered one report from them from January 2020 through May 2022. A DOT official said there are too few interference reports in the Safety Action Program data to routinely review these data. However, the official also told us that DOT does not review Safety Action Programs for potential interference reports unless someone in these programs calls attention to a report that requires review because it is related to an incident other users reported.

*NASA's ASRS.* We identified 72 reports of potential GPS interference that aviation users submitted to NASA's ASRS from January 2020 through December 2021.<sup>40</sup> A DOT official told us that aviators may submit reports of GPS interference to ASRS if they consider the incident to be a safety issue that has not been addressed. DOT and FAA officials told us that FAA may review ASRS reports on occasion after an incident has concluded to identify additional reports for the incident, but DOT does not consider these reports in its process. Officials said that DOT does

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<sup>39</sup> The Aviation Safety Action Program provides a way for employees of participating companies to identify and report safety issues to management and to the FAA for resolution. We did not review data from the Aviation Safety Action Program. These data are contained in databases maintained by designated administrators selected by each participating company. The Air Traffic Safety Action Program is a collaborative effort between the National Air Traffic Controllers Association and FAA and enables air traffic controllers to voluntarily identify and report safety and operational concerns. These data are collected and shared between aviation stakeholders through the Confidential Information Share Program and the Aviation Safety Information and Analysis Sharing. We did not review data from the Air Traffic Safety Action Program. Controllers we spoke to told us that they identified about 20 reports that mentioned interference in 2021 through an informal search of Air Traffic Safety Action Program data, but clarified that they did not review these reports to determine if they were specific to GPS interference or if there were additional reports in the data.

<sup>40</sup> ASRS is a NASA program that allows air traffic controllers and other aviation personnel to anonymously submit reports about safety incidents to support federal efforts to improve aviation safety. We reviewed reports of potential incidents within the U.S. We identified these incidents in the data with the assistance of NASA ASRS personnel. NASA does not verify or validate the accuracy of user reports in ASRS or investigate user reports. According to NASA officials, all reports should be treated as possible GPS interference, not confirmed interference. Reports should not be used to infer the prevalence of a problem within the National Airspace System. A NASA official told us that ASRS may contain some reports submitted through Aviation or Air Traffic Safety Action Programs.

not routinely consider these reports because NASA anonymizes them, so DOT cannot clarify information with the user. However, according to NASA, its review process allows information to be clarified during the review process before anonymizing the data, if needed.<sup>41</sup>

A DOT official also told us that the process does not include ASRS reports because users may submit reports to ASRS up to one month after an incident occurs, and as a result, they are not useful for identifying potential GPS interference in a timely manner. Yet, many of the reports DOT currently uses are submitted days or weeks after an incident occurs. On average, in 2020 and 2021, users submitted reports to NAVCEN between 15 and 19 days after an incident occurred, which DOT then used to identify incidents.<sup>42</sup>

ASRS reports may contain valuable information that could help DOT identify broader, ongoing interference issues and ensure it has the most complete information possible. For example, in data from January 2020 through December 2021, we identified at least two ASRS reports of possible recurrent interference, and at least two reports that appeared to be from pilots who experienced possible interference in the same area weeks apart. Additionally, ASRS reports could provide DOT with valuable insights into the extent to which planned interference affects GPS users. We found that users mentioned planned interference in about 40 percent of the reports of potential GPS interference submitted to ASRS from January 2020 through December 2021. According to the reports,

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<sup>41</sup> NASA officials explained that according to FAA guidance, reports are anonymized to encourage reporting of incidents that may involve potential regulatory violations to improve aviation safety. NASA officials noted that the FAA Advisory Circular No. 00-46F, provides that the filing of a report with NASA concerning an incident or occurrence involving a violation of 49 U.S.C. subtitle VII or title 14 of the Code of Federal Regulations to be indicative of a constructive attitude. Such an attitude will tend to prevent future violations. NASA officials explained that although a finding of violation may be made, neither a civil penalty nor a certificate suspension will be imposed if specific conditions identified in Advisory Circular No. 00-46F are met, such as if the person proves that within 10 days after the violation or date when the person became aware or should have been aware of the violation, they completed and delivered or mailed a written report of the incident or occurrence to NASA. FAA, *Advisory Circular No. 00-46* (Apr. 2, 2021), para. 12.3.

<sup>42</sup> ASRS data do not include the date the user submitted the report, so we were not able to determine the length of time between the incident and a user's report submission. A NASA official told us that NASA prioritizes reports involving potential GPS interference by screening reports within 3 to 5 days after they are submitted to determine if they involve possible GPS interference, among other things.

aviators who suspected planned interference reported experiencing effects such as flight into restricted airspace, missed landing approaches, and malfunctioning aircraft systems, among other issues.

**Inaccurate information on cause.** DOT's process does not result in accurate or complete information on whether the GPS problems users reported were actually caused by interference. DOT officials told us that DOT categorizes the suspected cause for potential GPS interference incidents based on its analysis of user reports before other federal agencies conduct their investigations, which we discuss in more detail below. We found that DOT categorized 21 of the 196 potential incidents it identified from January 2020 through May 2022 as caused by GPS interference. However, DOT officials told us that its categorization is often inaccurate. Officials said that FAA's data system for capturing incidents does not have a field that differentiates between incidents that were caused by GPS interference and those that were not, which may contribute to this inaccuracy.<sup>43</sup> Additionally, according to a DOT official, though other federal agencies may investigate suspected interference, DOT does not update its categorization of cause in the data with the outcomes of those investigations, including their final determination of whether interference actually occurred. DOT officials told us that in some instances DOT may not have access to information on some investigations' outcomes related to pending legal proceedings. Additionally, a DOT official told us that because DOT has not documented its process, a single individual knows how to review and analyze the user reports. Because one individual conducts the analysis, that individual does not also have time to update the data with a final cause. As a result, DOT does not have accurate information about the extent to which interference actually occurred.

**Duplicate records.** FAA and DOT officials estimated that about 30 percent of the total GPS interference reports in FAA's internal data system are duplicates, which are time consuming to correct. According to FAA officials, some level of duplication is unavoidable because multiple GPS users may report the same possible interference incident. However, one DOT official told us that FAA personnel often enter the same user report more than once, which means they are "true duplicates." A DOT official told us that the true duplicate entries were likely due to manual

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<sup>43</sup> This data system, a system of record for safety information in the National Airspace System, is called the Remote Monitoring and Logging System and FAA uses it to log user reports of GPS interference.

**Importance of Accurate Location Information for Federal Response to GPS Interference: Wheeling, IL Incident**

In January 2021, pilots began submitting reports to the Federal Aviation Administration's (FAA) online GPS anomaly reporting form that they were losing GPS signal in the vicinity of the Chicago Executive Airport. Based on initial reports, the Department of Transportation (DOT) estimated that the potential interference originated from within a roughly 51 nautical mile area around the airport.

After receiving additional reports, DOT narrowed the target area for federal investigators to an 8-by-14 nautical mile area.

In December 2021, the Federal Communications Commission (FCC) Enforcement Bureau, with FAA assistance, located the source of the interference—an illegal multi-band jammer—within 3.8 nautical miles of DOT's area of interest. Federal law enforcement confiscated the device.

Source: DOT officials and GAO analysis of DOT data. | GAO-23-105335

data entry by multiple personnel and the nonstop work environment in which FAA personnel entering the information operate, which limits their ability to determine if a report has already been entered. As a result, DOT must later remove duplicates by matching information across users' reports. We found that DOT removed more than 50 percent of the GPS interference reports FAA personnel logged from January 2020 through May 2022 when DOT reviewed and corrected the data.<sup>44</sup> Without a documented process that explains how GPS interference reports should be entered, DOT is limited in its ability to identify and implement controls to minimize duplicate records.

**Inaccurate location information.** FAA personnel often enter inaccurate location information when they log GPS users' reports in FAA's data system. Specifically, one DOT official told us that personnel enter the location of the operations center where they are located into the location field for each user report rather than the location of the possible interference, which is not reflected in the data. As a result, the DOT official who analyzes the data told us they have to review each users' narrative remarks to try to identify the actual or closest location where the incident occurred. We found that, even after updating the data with the location from the narratives, about 35 percent of the worldwide interference reports in DOT's data listed the location of FAA's operations center as the location of the incident. Because DOT uses the location information to identify a target area for federal investigators trying to locate the source of possible interference (see sidebar), inaccurate location information could affect federal agencies' ability to quickly locate and stop interference. A documented process would help FAA staff entering user reports have a clear understanding of how that information will be used and what they should enter to ensure the information is as accurate as possible.

DOT's process does not result in complete and accurate information because DOT has not yet documented the process to ensure it results in quality information, nor has DOT prioritized improvements to the process it currently uses. DOT officials told us that the process is relatively new and is still evolving, and that it is not guided by established policy documents. Instead, they said that one part-time staff member independently developed and began implementing the process in January 2020 using that individual's professional judgement. DOT developed the

<sup>44</sup> Due to data limitations, we were not able to determine the proportion of records that represented multiple user reports of the same incident compared to the proportion of records that were true duplicates.

process in preparation for the agency's responsibilities under SPD-7, because no other DOT office was reviewing interference reports across modes.<sup>45</sup> A DOT official said the agency is in the process of developing a document outlining the process and intends to complete it by the end of calendar year 2022. But, as of September 2022, it is not yet complete.

Without documenting this process, DOT is limited in its ability to identify and implement controls to ensure that it is completely and accurately identifying interference incidents. For example, because DOT has not documented its process, the staff member who developed and implements the process is the only individual who knows how it works. DOT officials told us that the agency has no additional staff who conduct the analysis or review the process or resulting data to ensure that it completely and accurately identifies interference incidents. DOT officials acknowledged that they need additional dedicated staff with the skills, training, and knowledge to conduct accurate analysis to identify GPS interference incidents. DOT requested funding to nearly double the number of PNT staff in fiscal year 2023.

Federal internal control standards state that agencies should document processes to retain organizational knowledge, mitigate the risk of having knowledge limited to a few personnel, and meet operational needs. These standards also state that agencies should produce quality information—including information that is complete and accurate—to inform decisions.<sup>46</sup> Without documenting the process it uses to review and analyze user reports of potential GPS interference, DOT lacks reasonable assurance that it provides complete and accurate information to support federal efforts to respond to and stop GPS interference. Given that DOT uses this information to support other federal agencies' investigations of GPS interference, without the most complete and accurate information possible, federal efforts to identify, locate, and stop GPS interference affecting transportation safety could be delayed.

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<sup>45</sup> DOT officials noted that under the previous national policy, NSPD-39, DHS had the lead responsibility for GPS interference detection. As a result, the responsibility to identify GPS interference incidents was new for DOT as of January 2021.

<sup>46</sup> [GAO-14-704G](#).



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## DOT Has Procedures to Share Information and Provide Assistance to Respond to Ongoing Interference Incidents

DOT responds to the potential interference incidents it identifies by sharing information with federal agency partners and supporting their efforts to investigate, locate, and stop interference. DOT is responsible for locating and attributing the source of interference adversely affecting users in the U.S.<sup>47</sup> To do so:

- DOT routinely shares information on user reports with other federal operations centers within DOT, DHS, DOD, and FCC to determine if possible interference is affecting multiple users and is causing significant effects.<sup>48</sup> According to officials, DOT shares its assessment of the incident's priority, operational impact, and the potential location of the interference source for each incident it identifies. DOT officials stated that when the agency shares this information, the other centers review whether they have related information, such as similar user reports, and may report back to DOT.
- DOT shares information, as needed, with the Purposeful Interference Response Team (PIRT), a non-operational interagency team that coordinates the overall federal response to GPS interference.<sup>49</sup> When determining whether to escalate incidents within the PIRT, DOT and the other operations centers are to consider whether an incident meets certain criteria such as the extent to which the incident affects

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<sup>47</sup> SPD-7 (2021). This is part of the requirement that DOT monitor, identify, locate, and attribute GPS disruptions adversely affecting users in the U.S. DOT officials noted that this is a new responsibility for DOT as of January 2021. We evaluated DOT's efforts to respond to interference separately from its efforts to identify GPS interference incidents because DOT has different procedures in place to respond, and it is a different step in the sequential process to address GPS interference.

<sup>48</sup> Specifically, DOT officials told us that DOT routinely shares the information on incidents it identifies with the FAA Operations Control Center within DOT, the National Coordinating Center for Communications and NAVCEN within DHS, the GPS Operations Center within DOD, and the FCC Operations Center. DHS officials told us that in draft interagency agreements, the National Coordinating Center for Communications will be changed to the Cybersecurity and Infrastructure Security Agency.

<sup>49</sup> DOT is one of seven core agencies that make up this team, and these agencies are responsible for reporting, investigating, and developing recommended actions to respond to suspected intentional interference. DOT is represented by the FAA and the Maritime Administration and, according to DOT officials, OST-R. Other core members include representatives from various offices within DOD, DHS, FCC, as well as the Departments of State and Commerce and the Office of the Director of National Intelligence. In addition to the core members, the team may include any of 13 conditional members from across the federal government, as needed.

**Department of Transportation (DOT)  
Identification and Response to GPS  
Interference Incident: Wilmington, North  
Carolina**

Starting in June 2020, pilots and air traffic controllers reported that aircraft were losing GPS signals within 25 miles of the Wilmington Airport. More than half a dozen pilots reported these disruptions to air traffic controllers and to the Federal Aviation Administration's (FAA) online GPS anomaly reporting form between June and September 2020. After identifying the incident as potential GPS interference, FAA notified pilots that they should expect to lose GPS signals in the area.

In January 2021, working together with the Federal Communications Commission (FCC), FAA investigated and determined that a local public utility had placed wireless control system emitters on power line poles around the airport. According to an industry stakeholder involved in resolving the interference, these emitters included a faulty antenna that operated on a radio frequency that interfered with the GPS signal. FAA and FCC worked with the utility to adjust the antenna and resolve the unintentional interference.

Source: GAO Review of DOT data and news articles. | GAO-23-105335

users across critical infrastructure sectors, operational impacts, and whether the interference could be intentional. DOT officials told us that they follow the processes for responding to interference incidents

- that are laid out in the PIRT charter, annexes, and various interagency memorandums of agreement.<sup>50</sup>

When a coordinated federal response is needed, DOT may support other agency partners as they investigate suspected GPS interference incidents to identify the source and stop the interference.<sup>51</sup> While such investigations may be initiated for suspected intentional interference, they may ultimately uncover unintentional interference (see sidebar). Federal agencies' investigations of potential interference can be lengthy and resource intensive. For example, when interference began affecting operations at Newark Airport in late 2009, it took DOT and other federal, state, and local partners nearly 18 months to identify, locate, and stop the interference. The investigation required officials to stand on an overpass above interstate 95 with radiofrequency measurement devices to identify a vehicle carrying a jamming device. The driver of the vehicle surrendered the device at a traffic stop.

While federal investigations into interference may take months, in some cases, FAA may respond immediately using established procedures in its orders and manuals to assist pilots and ensure that aircraft can continue to operate safely. According to FAA's manual, if pilots experience a GPS disruption, they should report the situation over voice radio to air traffic control. FAA's orders state that in response, air traffic controllers may provide special assistance, such as voice commands, to ensure that aircraft can operate safely until they recover a GPS signal or can land. For example, one air traffic controller reported to NASA's ASRS that in 2018, air traffic controllers helped an aircraft in Idaho that had lost GPS avoid a near collision with a mountain by issuing verbal directions to the pilot. If air traffic control receives reports of GPS disruptions or outages from multiple pilots, FAA orders direct controllers to inform other aircraft that they may lose GPS in the area (see sidebar).

<sup>50</sup> For example: *Purposeful Interference Response Team (PIRT) Charter, Organization and Operational Guidelines* (December 2020); *Interagency Memorandum of Agreement with Respect to the Support of Users of The Navstar Global Positioning System* (June 2017); and *Interagency Task Force (IATF) Agreement Between the DOT/FAA and the Department of Justice/Federal Bureau of Investigation and the FCC* (August 1989).

<sup>51</sup> According to DOT officials, DOT accomplishes this mission jointly with FCC which has regulatory oversight authority of non-government sources of interference. For more information, see footnote 28.

**Department of Transportation (DOT)  
Identification and Response to GPS  
Interference Incident: Denver, CO**

According to DOT officials, on the afternoon of January 21, 2022, pilots and train operators in the Denver area began reporting GPS disruptions via the Federal Aviation Administration's (FAA's) and U.S. Coast Guard Navigation Center's online GPS reporting forms. Operators reported that the disruptions were affecting safety-critical operations.

To support federal efforts to address the possible interference, FAA shared the reports with a federal interagency response team, which escalated the incident. DOT also identified an initial target area to search for the interference source and shared this information with the Federal Communications Commission's (FCC) Enforcement Bureau to support FCC's field response. In addition to information from DOT, FCC officials said FCC had also received additional complaints. In response, FCC located the source of the interference and resolved the incident on the evening of January 22, 2022.

Source: DOT and FCC officials. | GAO-23-105335

FAA may also respond immediately during planned interference events if an event is affecting safety. Specifically, if air traffic control receives reports from multiple aircraft that planned GPS interference is affecting safety, controllers may issue a request to stop the event, called a stop buzzer. DOD will then stop testing to ensure aircraft can operate safely.<sup>52</sup> For example, DOT officials told us that over a 2-hour period in February 2021, about 40 pilots contacted air traffic controllers about GPS disruptions in the Yuma, Arizona area due to planned interference. DOT officials told us that air traffic controllers managed aircraft movements during this 2-hour period, but ultimately requested a stop buzzer due to safety concerns caused by increased workload. According to FAA, it initiated stop buzzers during 71 of the nearly 780 planned interference events DOD conducted from January 2017 through March 2022.<sup>53</sup>

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## DOT Has Taken Actions Intended to Improve Resilience in the Transportation Sector but Lacks a Strategic Approach to Guide Its Efforts

DOT has multiple recent and ongoing efforts intended to improve PNT resilience in the transportation sector. DOT took many of these actions in response to requirements in federal laws or policies. According to DOT officials, DOT has taken actions in response to all federal requirements to improve PNT resilience in the transportation sector. See appendix III for a full description of how DOT has responded to all federal PNT requirements. Specifically, as the agency responsible for improving PNT resilience in the transportation sector, DOT has conducted research and testing, engaged with the GPS user community, and taken steps to improve GPS signals and ensure continuity of operations. Table 4 lists examples of DOT's actions.

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<sup>52</sup> Procedures for air traffic control planning, coordination, and services during defense activities and special operations are specified in FAA, *Special Operations*, Order 7610.4V (Aug. 15, 2019).

<sup>53</sup> FAA officials told us that FAA issued 779 Notices to Air Missions for planned GPS interference. However, officials told us that in some cases more than one notice may have been issued for the same planned interference event, so the total number of planned events may be less than the number of notices issued.

**Table 4: Examples of Department of Transportation (DOT) Actions to Improve Positioning, Navigation, and Timing (PNT) Resilience in the Transportation Sector**

Type of action	DOT actions	Action taken in response to federal requirement
Research	Studied backup and complements to GPS with the Department of Homeland Security (DHS).	DOT action is in response to a federal requirement
	Funds research on PNT resilience, risk mitigation strategies, and PNT technologies for highly automated transportation systems and automated vehicles.	Other DOT action intended to improve PNT resilience
Testing	Conducted field demonstrations of PNT technologies that could offer complementary PNT service in the event of GPS disruptions.	DOT action is in response to a federal requirement
	Tested vulnerabilities and complementary PNT technologies with the Maritime Administration.	DOT action is in response to a federal requirement
	Is assessing and testing PNT vulnerabilities in the aviation, rail, and maritime modes.	DOT action is in response to a federal requirement
Engaging with the GPS user community	Chairs a committee for the civil GPS user community to exchange information on PNT resilience, among other things.	Other DOT action intended to improve PNT resilience
	Hosted a workshop on jamming and spoofing in the maritime environment, including discussions of complementary PNT technologies.	DOT action is in response to a federal requirement
	Collaborates with stakeholders to help develop standards for resilient PNT user equipment.	Other DOT action intended to improve PNT resilience
Improving GPS signals and ensuring continuity of operations	Is working to make additional GPS signals available to civil users with the Department of Defense.	DOT action is in response to a federal requirement
	Is working to authenticate civil GPS signals in coordination with DOD and DHS.	DOT action is in response to a federal requirement
	Participates in interagency notification mechanisms to help ensure continuity of operations in the event of GPS disruptions.	DOT action is in response to a federal requirement

Legend:  
 ✓ = DOT action is in response to a federal requirement  
 ● = Other DOT action intended to improve PNT resilience

Source: GAO analysis of information provided by DOT. | GAO-23-105335

Note: DOT took some of these actions in response to federal requirements, such as Executive Order 13905 and Space Policy Directive 7. For the full list of federal requirements and actions taken, see appendix III.

While DOT has taken actions, DOT officials could not clearly explain how DOT’s current efforts have improved PNT resilience, nor do key

stakeholders agree on the status of PNT resilience in the transportation sector and the work that remains to achieve resilience. Several federal studies we reviewed reached opposite conclusions regarding the extent to which the transportation sector is resilient to GPS interference. For example, DHS found that there are existing backups or workarounds that could limit the impact of GPS interference, and that given the challenges to adopting these backups, federal investment in a single backup system is not the most effective action the federal government could take to enhance PNT resilience.<sup>54</sup> Conversely, RTCA, in a report FAA commissioned, found that FAA's current plan for GPS backups to support aircraft operations in the event of a GPS disruption is insufficient and recommended maintaining legacy systems.<sup>55</sup> Similarly, DOT officials and a few of the external stakeholders we spoke to said that the U.S. transportation sector is not resilient to GPS interference and much work remains. However, other federal and external stakeholders we spoke to told us that at least some transportation modes have sufficient backups to withstand GPS interference.

The lack of clarity and consensus on the status of PNT resilience in the transportation sector and the work that remains may be, in part, because DOT has not taken a strategic approach to managing its PNT resilience efforts. DOT officials told us that the agency does not currently have a plan that guides all of its PNT resilience efforts, though DOT has taken steps to guide some of its efforts. For example, in August 2022, DOT finalized an implementation document describing how its PNT research and development activities align with objectives in the National Research

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<sup>54</sup> DHS, *Report on Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS)* (Apr. 8, 2020).

<sup>55</sup> RTCA, *Operational Impacts of Intentional GPS Interference* (March 2018). FAA's current plan is to rely on legacy navigation systems to serve as a backup in the event of a GPS disruption. RTCA is a non-profit organization that develops technical guidance for use by government regulatory authorities and industry. RTCA made two recommendations to FAA related to the decommissioning of legacy navigation systems, including that (1) FAA should maintain the minimum operating network of legacy equipment and that (2) FAA should coordinate with industry to develop a strategy for decommissioning secondary-surveillance radar systems. FAA concurred with the first recommendation but did not concur with the second one. FAA reported to RTCA in 2021 that it considered both recommendations closed.

and Development Plan for PNT Resilience.<sup>56</sup> However, the implementation document is the only guiding document we identified that DOT has developed specifically to manage its PNT resilience efforts, which DOT considers part of its PNT management program.<sup>57</sup>

OMB guidance has identified the importance of strategic program management to help ensure federal agencies' programs effectively achieve their goals and objectives.<sup>58</sup> OMB has also identified other detailed program management standards that could help agencies implement a strategic approach, including the PMI® standards for program management.<sup>59</sup> According to key PMI® standards, a strategic approach to manage programs should: (1) define objectives the program hopes to accomplish; (2) outline and prioritize planned actions to achieve objectives; and (3) plan for addressing challenges to achieving objectives. PMI® identifies specific elements for each of these standards.<sup>60</sup> Implementing an approach that meets these standards can help agencies clarify desired outcomes of programs, assess progress toward achieving

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<sup>56</sup> DOT, *DOT Implementation Activities Supporting the National Research and Development Plan for Positioning, Navigation & Timing (PNT) Resilience* (August 2022). The National Science and Technology Council developed the *National Research and Development Plan for Positioning, Navigation and Timing Resilience* (August 2021) in response to a requirement in E.O. 13905 for the Office of Science and Technology Policy to develop a national research and development plan. This plan outlines 14 research and development objectives to improve PNT resilience and identifies which federal agencies should support those objectives. DOT participated in the development of the plan and identified the objectives that applied to DOT's activities.

<sup>57</sup> FAA has developed a navigation strategy that seeks to ensure alternative sources of PNT information are available to aviators during GPS disruptions. Because this strategy pertains only to aviation and does not include DOT's PNT resilience efforts for the overall transportation sector, we did not assess it. FAA, *Performance Based Navigation Strategy* (2016).

<sup>58</sup> OMB, M-18-19. We previously reported that the OMB M-18-19 standards are not detailed compared with accepted program and project management standards, such as those developed by PMI®. We also reported that OMB staff previously said they chose the approach to provide more principle-based standards in OMB M-18-19, as opposed to specific standards, to be flexible enough for a range of government agencies to apply them. [GAO-20-44](#).




<sup>59</sup> PMI®, *The Standard for Program Management*, Fourth Edition (2017). OMB encourages agencies to use program management standards that have been developed and endorsed by other program management standards bodies provided they align with the standards in OMB M-18-19. PMI® is one such set of standards.




<sup>60</sup> We reviewed PMI® standards and selected elements that are consistent with, but elaborate on, the strategic planning standards in OMB M-18-19.

goals, identify needed resources, and navigate challenges, among other benefits.

DOT’s approach to PNT resilience—which DOT has identified as part of its PNT management program—does not fully align with these key standards. Since DOT does not have a strategic plan guiding its overall PNT resilience efforts, we assessed documents that DOT officials told us comprise the agency’s current approach. These documents include DOT’s R&D implementation document and its fiscal year 2022 budget justification. When we assessed DOT’s approach to PNT resilience against key PMI® standards, we found that it partially aligned with two of the standards and did not align with one of the standards. See figure 4 for our assessment of DOT’s approach to PNT resilience.

**Figure 4: Assessment of the Department of Transportation’s (DOT) Approach to Improve Positioning, Navigation, and Timing (PNT) Resilience against Key Standards for Strategic Program Management.**

Key Standard <sup>a</sup>	GAO Assessment of DOT’s Approach against the Standard <sup>b</sup>
<p><b>Define objectives the program hopes to accomplish</b></p> 	<ul style="list-style-type: none"> <li>• DOT’s research and development (R&amp;D) implementation document identifies objectives that generally align with DOT’s broader goals and objectives.<sup>c</sup> The document also describes the expected benefits of some of its PNT resilience efforts but does not clearly define success.</li> <li>• With regard to its broader PNT activities, DOT officials told us they consider federal requirements, definitions, and principles established by other agencies and bodies, and use DOT’s budget process to guide its efforts. However, these documents do not clearly establish objectives for PNT resilience in the transportation sector.</li> </ul>
<p><b>Outline and prioritize planned actions to achieve objectives</b></p> 	<ul style="list-style-type: none"> <li>• DOT’s R&amp;D implementation document clearly identifies how its PNT resilience efforts align with each of the objectives. The document also discusses linkages between some, but not all, of DOT’s resilience efforts, but does not prioritize efforts.</li> <li>• With regard to its broader PNT activities, DOT described linkages between some of its PNT resilience efforts through DOT’s budget process. However, DOT has not documented how its collective planned actions will achieve objectives or prioritized its PNT resilience efforts.</li> </ul>
<p><b>Plan for addressing challenges to achieving objectives</b></p> 	<ul style="list-style-type: none"> <li>• DOT’s R&amp;D implementation document does not describe how DOT monitors or will respond to challenges to achieving its objectives for PNT resilience.</li> <li>• With regard to its broader PNT activities, DOT has not documented how it monitors or will respond to challenges to achieving its objectives for PNT resilience.</li> </ul>

 Met: DOT’s approach fully aligned with all elements of the standard.
  Partially Met: DOT’s approach aligned with some, but not all elements of the standard.
  Not Met: DOT’s approach did not align with any elements the standard.

Source: GAO analysis of DOT information. | GAO-23-105335

**Text of Figure 4: Assessment of the Department of Transportation’s (DOT) Approach to Improve Positioning, Navigation, and Timing (PNT) Resilience against Key Standards for Strategic Program Management.**

Key Standard	Evaluation	GAO Assessment of DOT’s Approach against the Standard /b/
Define objectives the program hopes to accomplish	Partially Met: DOT’s approach aligned with some, but not all elements of the standard.	<ul style="list-style-type: none"> <li>DOT’s research and development (R&amp;D) implementation document identifies objectives that generally align with DOT’s broader goals and objectives./c/ The document also describes the expected benefits of some of its PNT resilience efforts but does not clearly define success.</li> <li>With regard to its broader PNT activities, DOT officials told us they consider federal requirements, definitions, and principles established by other agencies and bodies, and use DOT’s budget process to guide its efforts. However, these documents do not clearly establish objectives for PNT resilience in the transportation sector.</li> </ul>
Outline and prioritize planned actions to achieve objectives	Partially Met: DOT’s approach aligned with some, but not all elements of the standard.	<ul style="list-style-type: none"> <li>DOT’s R&amp;D implementation document clearly identifies how its PNT resilience efforts align with each of the objectives. The document also discusses linkages between some, but not all, of DOT’s resilience efforts, but does not prioritize efforts.</li> <li>With regard to its broader PNT activities, DOT described linkages between some of its PNT resilience efforts through DOT’s budget process. However, DOT has not documented how its collective planned actions will achieve objectives or prioritized its PNT resilience efforts.</li> </ul>
Plan for addressing challenges to achieving objectives	Not Met: DOT’s approach did not align with any elements the standard.	<ul style="list-style-type: none"> <li>DOT’s R&amp;D implementation document does not describe how DOT monitors or will respond to challenges to achieving its objectives for PNT resilience.</li> <li>With regard to its broader PNT activities, DOT has not documented how it monitors or will respond to challenges to achieving its objectives for PNT resilience.</li> </ul>

Source: GAO analysis of DOT information. | GAO-23-105335

<sup>a</sup>We selected standards for a strategic approach to program management from the Project Management Institute’s *The Standard for Program Management*, Fourth Edition (2017). We selected standards that aligned with the Office of Management and Budget’s guidance on federal program management. See OMB, *Improving the Management of Federal Programs and Projects through Implementing the Program Management Improvement Accountability Act*, M-18-19 (Washington, D.C.: June 25, 2018). We identified specific elements to operationalize each standard and assess DOT’s approach.

<sup>b</sup>We assessed documents and principles DOT officials told us comprise the agency’s approach to PNT resilience.

<sup>c</sup>DOT, *DOT Implementation Activities Supporting the National Research and Development Plan for Positioning, Navigation & Timing (PNT) Resilience* (August 2022). DOT developed this document to implement the National Research and Development Plan for PNT Resilience. National Science and Technology Council, *National Research and Development Plan for PNT Resilience*, (August 2021).

Because DOT does not have a strategic approach that fully defines objectives for its PNT resilience efforts, DOT is limited in its ability to assess progress toward improving resilience in the transportation sector. When asked what objectives DOT has identified for PNT resilience in the transportation sector, DOT officials told us that the agency considers the PNT Advisory Board’s “protect, toughen, augment” principles when it implements its PNT resilience efforts; however, officials were unable to



demonstrate how DOT has applied these principles to guide its approach. Specifically, DOT officials told us that these principles were reflected in DOT's budget request, but when we reviewed the request, we did not identify any discussion of these principles as they relate to DOT's objectives for PNT resilience. DOT officials also told us that defining and measuring PNT resilience in the transportation sector is challenging because technology, threats, and sector needs are continuously evolving. For example, DOT officials said that since it initially assessed PNT vulnerabilities in 2001, the threats to GPS have changed, requiring new approaches. However, the fluid nature of resilience makes it all the more important that DOT identifies specific objectives for all of its PNT resilience efforts so it can continually assess and communicate its progress toward resilience.

Additionally, because DOT has not prioritized planned actions to improve PNT resilience, DOT may be limited in its ability to identify and allocate resources to the activities it determines are most significant. DOT officials told us their ability to meet the many demands federal policy has long placed on the agency to improve PNT resilience has been limited due to insufficient funding, but told us that DOT has not sought additional funding for resilience efforts until recently. According to DOT officials, between fiscal years 2015 and 2021, DOT's requested and allocated funding to implement specific PNT activities, including resilience activities, remained about the same.<sup>61</sup> In fiscal year 2022, when DOT requested additional funding to meet PNT requirements, Congress directed more than the requested funds for DOT to conduct these activities. Without a strategic approach that prioritizes and identifies linkages between its PNT resilience efforts, DOT may not be able to effectively leverage existing resources or justify the need for additional resources it believes are necessary to improve PNT resilience.

Further, recognizing and planning for challenges is especially important in light of the longstanding challenges to improving PNT resilience that DOT and others, including GAO, have identified (see app. II). For instance, DOT officials pointed out that the private sector is unlikely to invest or

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<sup>61</sup> PNT resilience activities are funded from DOT's Research and Technology appropriation (OST-R). From fiscal years 2015 through 2017, DOT's budget request included an explicit request for PNT funding. For fiscal years 2018 through 2023, DOT's budget request did not explicitly contain a line item for PNT. However, DOT officials said that as of fiscal year 2018, the agency requests PNT funding as part of the Research and Technology Programs request. Officials told us that for fiscal years 2018 through 2022, DOT allocated money to PNT as part of the Research Priorities allocation of the OST-R appropriation.

demand federal investment in PNT resilience until a major disruption occurs because GPS users may see disruptions as a low consequence event. Nonetheless, DOT has identified potentially serious safety effects if such a disruption were to occur. Without a strategic approach that clearly identifies and plans for such challenges, DOT may be limited in its ability to identify opportunities to persuade private sector stakeholders to take steps to improve resilience.<sup>62</sup>

While DOT does not currently have a strategic approach that aligns with program management standards, DOT officials told us that the agency is in the process of developing a strategy. Officials said they anticipate the strategy will guide all of DOT's PNT activities, including PNT resilience, to meet current and future transportation needs. As of September 2022, DOT is working to identify goals and priorities for its PNT resilience efforts, but we did not evaluate DOT's draft strategy against the PMI® standards because it is not yet complete. DOT officials told us the agency anticipates circulating a complete draft of its strategy for internal review and approval in early 2023. As DOT continues to develop its strategy, ensuring that it aligns with strategic program management standards could improve the agency's ability to measure progress, identify priorities, and address challenges to achieving a more resilient transportation sector.

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## Conclusions

DOT has determined that GPS interference has the potential to harm transportation safety across all modes. Federal policy and DOT both recognize that there are critical steps DOT can take to mitigate the potential harmful effects of GPS interference. The ability for DOT to (1) quickly identify and respond to GPS interference incidents as they occur and (2) ensure transportation infrastructure is resilient to future GPS interference is vital to maintain transportation safety. Yet the process DOT currently uses to identify potential interference incidents affecting transportation safety does not result in complete or accurate information because DOT has not documented the process. Without doing so, the agency is limited in its ability to improve the process it uses, including ensuring that the process results in quality information. As a result, DOT and its federal partners may not be acting on the most complete or accurate information available when they must locate and stop harmful interference.

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<sup>62</sup> PMI®, *The Standard for Program Management*, Fourth Edition (2017).

Additionally, while DOT has taken some steps to plan its PNT resilience work, the extent to which its actions have improved resilience is unclear because DOT has not taken a strategic approach that could help the agency address challenges and achieve its goals. Nonetheless, DOT has made clear that improving PNT resilience is critical to reducing deaths and injuries across all modes of transportation and ensuring that America's transportation network continues to be safe and technologically advanced. DOT has also recognized the potential for severe impacts on transportation safety if a significant interference incident were to occur. Though DOT is working to develop a strategic plan for its PNT activities, without a more strategic approach, neither the agency, nor key transportation stakeholders, have a clear understanding of how resilient the sector is and the work that remains to ensure that such severe impacts can be mitigated in the future. As transportation technologies evolve and increasingly depend on GPS to support critical safety functions, it is all the more important that DOT have processes and strategies in place to support robust interference detection and proactively improve PNT resilience.

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## Recommendations for Executive Action

We are making the following two recommendations to DOT:

The Secretary of DOT should ensure the Assistant Secretary for Research and Technology documents DOT's process to identify GPS interference incidents affecting transportation safety across modes, including identifying the necessary controls and data sources to ensure that the process results in complete and accurate information.

(Recommendation 1)

The Secretary of DOT should ensure the Assistant Secretary for Research and Technology develops a strategic approach to PNT resilience that fully aligns with key standards for a strategic approach to program management, including identifying objectives, outlining and prioritizing activities to achieve those objectives, and planning to address challenges. (Recommendation 2)

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## Agency Comments

We provided a draft of this report to the Secretary of Transportation, the Secretary of Homeland Security, the Secretary of Defense, the Secretary of Commerce, the Administrator of NASA, and the Chair of FCC for

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review and comment. In its comments, reproduced in appendix IV, DOT agreed with our recommendations. DOT, DHS, Commerce, NASA, and FCC also provided technical comments, which we incorporated as appropriate. DOD told us that they had no comments on the draft report.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or [KrauseH@gao.gov](mailto:KrauseH@gao.gov). Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

A handwritten signature in black ink that reads "Heather Krause". The signature is written in a cursive style with a large, looping initial "H".

Heather Krause,  
Director, Physical Infrastructure

## Appendix I: Objectives, Scope, and Methodology

This report (1) describes any potential effects of GPS interference incidents on transportation safety the Department of Transportation (DOT) has identified; (2) assesses DOT's processes to identify and respond to GPS interference incidents in the transportation sector as they occur; and (3) assesses DOT's approach to improving the resilience of the transportation sector to future GPS interference incidents.

To address all objectives, we reviewed federal requirements, DOT policies, and interagency agreements and documents governing federal GPS management, including executive orders, memos, and statutes.<sup>1</sup> We interviewed officials and reviewed documents from DOT and some of its operating administrations, including the Federal Aviation Administration (FAA); the Federal Railroad Administration (FRA); and the Maritime Administration (MARAD). We also interviewed officials and reviewed documents from eight other federal agencies and entities that work with DOT to manage GPS, such as the Department of Defense (DOD); the Department of Homeland Security (DHS); the National Aeronautics and Space Administration (NASA); and the National Space-Based Positioning, Navigation, and Timing Executive Committee (EXCOM), among others.<sup>2</sup>

In addition, for all objectives we selected and interviewed representatives from four aviation industry stakeholders and one rail industry stakeholder to obtain their operational perspectives on the effects of GPS interference, mitigation measures, reporting mechanisms, and ways to improve positioning, navigation, and timing (PNT) resilience specific to their mode. We also selected and interviewed one GPS industry stakeholder to obtain their perspective on the resilience of GPS user equipment. Additionally, we selected and interviewed seven sets of

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<sup>1</sup> Examples of federal requirements we reviewed include: Exec. Order No. 13905, 85 Fed. Reg. 9,359, (Feb. 18, 2020); Memorandum on Space Policy Directive 7 (SPD-7) (2021); and National Timing Resilience and Security Act of 2018, Pub. L. No. 115-282, § 514, 132 Stat. 4192, 4276-4279 (2018).

<sup>2</sup> Within EXCOM, we interviewed officials from the National Coordination Office. We also interviewed officials from the National Telecommunications and Information Administration and the National Institute of Standards and Technology, and received written responses from the National Oceanic and Atmospheric Administration and the Federal Communications Commission (FCC).

research stakeholders who are involved in research or technical standards development (PNT researchers): two focused on the aviation sector, one on maritime, and four not specific to a mode.<sup>3</sup> We obtained their perspectives on interference detection, standards setting, and ways to improve resilience to GPS interference. We selected more aviation stakeholders to interview relative to other modes because of the large number of actors involved in addressing GPS interference in the aviation sector (e.g., pilots, air traffic controllers, etc.); the response mechanisms available; and the potential safety risks compared to other modes. We selected the industry stakeholders and PNT researchers based on published work and recommendations from stakeholders, and to obtain perspectives from different transportation modes, among other factors.<sup>4</sup>

To describe the potential effects of GPS interference on transportation safety that DOT has identified, we reviewed eight studies DOT conducted or participated in and used to understand these potential effects.<sup>5</sup> We identified these studies by determining which studies DOT has used to inform its understanding of the potential effects of GPS interference on transportation safety. Specifically, we reviewed two DOT studies, including a 2001 assessment of GPS vulnerabilities in transportation infrastructure and a 2018 analysis of the effects of unintentional GPS interference on transportation from devices operating in nearby radiofrequencies.<sup>6</sup> We also reviewed three FAA technical reviews of

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<sup>3</sup> We refer to these as “sets” of researchers because we held one meeting to interview multiple individuals based on their membership or participation in standards setting or research organizations. The perspective each individual provided was representative of the individual’s own views and experiences, and not necessarily the organization of which each was a member.

<sup>4</sup> We refer to the industry stakeholders and PNT researchers we interviewed collectively as “external stakeholders.”

<sup>5</sup> While there is a substantial amount of research and literature available on GPS interference and its effects, the purpose of our review was to understand the potential effects of GPS interference that DOT has identified. As a result, we reviewed studies that DOT conducted or contributed to, and that DOT officials told us DOT used to inform its understanding of potential interference effects.

<sup>6</sup> Volpe Center, *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System* (Aug. 29, 2001). The Volpe Center prepared this report for DOT. DOT, *Global Positioning System (GPS) Adjacent Band Compatibility Assessment* (April 2018).

interference effects on aviation safety.<sup>7</sup> Additionally, we reviewed three GPS risk assessments and federal planning documents conducted or commissioned by other agencies or bodies to which DOT contributed.<sup>8</sup> We also drew on our interviews with external stakeholders to corroborate or further describe potential effects DOT identified.

To assess DOT's processes to identify and respond to GPS interference incidents in the transportation sector, we reviewed DOT's process to obtain and analyze user-reported data to identify interference incidents by interviewing relevant DOT and FAA officials. We assessed the extent to which this process was documented and resulted in quality information. To do so, we analyzed DOT's and other agencies' user-reported data on GPS interference incidents. Specifically, we reviewed DOT's Office of the Assistant Secretary for Research and Technology's (OST-R) consolidated GPS anomaly data, NASA's Aviation Safety Reporting System (ASRS) data, and the U.S. Coast Guard's Navigation Center's (NAVCEN's) GPS problem reporting data, all of which consist of user reports. We sought to review data from 2017 to the most current data available.<sup>9</sup> We assessed the reliability of these data by, among other things, reviewing these data for completeness and consistency, reviewing agency documentation, and interviewing agency officials responsible for managing these data. We found these data to have some limitations, but they were reliable for our purposes of describing the number and type of reports users submitted.

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<sup>7</sup> FAA, *Operational Safety Assessment Global Positioning System for Aviation* (Oct. 4, 2019) and *GNSS Intentional Interference and Spoofing Briefing* (Oct. 23, 2015). This briefing summarized a broader research effort by FAA. We primarily reviewed the briefing but consulted materials from the broader effort for context and details where needed. RTCA, *Operational Impacts of Intentional GPS Interference* (March 2018). FAA asked the RTCA's Tactical Operations Committee to study the impacts of planned interference on aviation on its behalf.

<sup>8</sup> DHS, *National Risk Estimate: Risks to U.S. Critical Infrastructure From Global Positioning System Disruptions* (November 2012); DOD, DHS, and DOT, *2021 Federal Radionavigation Plan* (2022); and Homeland Security Operational Analysis Center, *Analyzing a More Resilient National Positioning, Navigation, and Timing Capability* (2021). The Homeland Security Operational Analysis Center research was commissioned by DHS, but DHS officials told us that DHS did not concur with all the findings and that this report does not represent the official position of DHS. DOT contributed to and, according to DOT officials, uses the results of these studies to inform its understanding of the effects of GPS interference. As a result, we reviewed the studies and include them when we refer to "DOT studies".

<sup>9</sup> DOT was able to provide data from January 2020 through May 2022 because it started analyzing the data in January 2020. We reviewed user reports submitted to NAVCEN from January 2017 through January 2022 and user reports submitted to ASRS from January 2017 through December 2021.

Additionally, we interviewed external stakeholders to obtain a better understanding of how users report interference and the limitations associated with these reports.

We compared DOT's incident identification process and the results of our data analysis to DOT's responsibilities in federal policy.<sup>10</sup> We also determined that the control activities and information and communication components of internal control standards were significant to this objective, including the underlying principles for documentation and processing data into quality information.<sup>11</sup> Additionally, we reviewed DOT and interagency documentation and interviewed officials to understand how DOT and its operating administrations respond to the GPS interference incidents DOT identifies.

To assess DOT's approach to improving the resilience of the transportation sector to GPS interference, we reviewed documentation of DOT's actions to improve PNT resilience in the transportation sector, such as actions taken in response to federal requirements. We also interviewed DOT officials on DOT's approach to improving PNT resilience. To ensure we used a consistent definition for PNT resilience and because we could not identify a single federal definition for PNT resilience, we developed a definition based on federal policies and guidance.<sup>12</sup> We then identified the federal laws and policies that require DOT to take actions intended to improve PNT resilience in the transportation sector based on our definition and associated criteria.<sup>13</sup>

We assessed documents that DOT officials told us comprise the agency's current approach to PNT resilience—which DOT has identified as part of

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<sup>10</sup> SPD-7 (2021): Sec. 7. (d)(viii). DOT is required to monitor, identify, locate, and attribute GPS disruptions in the U.S. that adversely affect transportation safety. We evaluated DOT's processes to identify (related to monitoring and identifying) incidents separately from its processes to respond (related to locating and attributing) because DOT has different procedures for these respective steps and because they represent different steps in a sequential process.

<sup>11</sup> GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: Sep. 2014).

<sup>12</sup> We based our definition of "PNT resilience" on the following documents: White House, *Critical Infrastructure Security and Resilience*, Presidential Policy Directive/PPD-21 (Feb. 12, 2013); DHS, *Resilient PNT Conformance Framework* (Apr. 26, 2022); and National Science and Technology Council, *National Research and Development Plan for PNT Resilience* (August 2021).

<sup>13</sup> We confirmed our assessment with DOT officials.



its PNT program—against key standards for program management.<sup>14</sup> Specifically, we reviewed the Office of Management and Budget’s (OMB) federal strategic planning guidance, which identifies high-level standards and principles federal agencies should consider when managing programs.<sup>15</sup> Because OMB allows agencies to follow more detailed standards developed by external voluntary consensus standards bodies, we reviewed the Project Management Institute’s (PMI®) standards for a strategic approach to program management. We selected PMI® standards that corresponded to the strategic program management standards in OMB’s guidance.<sup>16</sup> Since the three standards we selected are key for a strategic approach to program management, we refer to them as “key standards.” These key standards include: define objectives, prioritize actions, and plan for addressing challenges. We identified specific elements to operationalize each standard for our assessment.<sup>17</sup> Additionally, we interviewed agency officials and external stakeholders to obtain their perspectives on challenges to improving PNT resilience, and reviewed 15 reports conducted or commissioned by federal agencies involved in GPS management to identify similar challenges. See appendix II for information on these challenges.

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<sup>14</sup> For example, we assessed DOT’s research and development implementation document and budget documents, among others. DOT, *DOT Implementation Activities Supporting the National Research and Development Plan for Positioning, Navigation & Timing (PNT) Resilience* (August 2022).

<sup>15</sup> OMB, *Improving the Management of Federal Programs and Projects through Implementing the Program Management Improvement Accountability Act*, M-18-19 (Washington, D.C.: June 25, 2018).

<sup>16</sup> Project Management Institute, Inc. (PMI®), *The Standard for Program Management*, Fourth Edition (2017). PMI® is a registered mark of the Project Management Institute, Inc. In December 2019, GAO reported that agencies could benefit from more detailed standards than those in M-18-19, and that OMB’s standards and principles are similar to PMI’s® program management standards. GAO, *Improving Program Management: Key Actions Taken, but Further Efforts Needed to Strengthen Standards, Expand Reviews, and Address High-Risk Areas*, [GAO-20-44](#) (Washington, D.C.: Dec. 13, 2019). We identified the PMI® program management standards that are consistent with, but elaborate on, the strategic planning standards in OMB M-18-19.

<sup>17</sup> The elements of each respective standard include: (1) define program-specific objectives, align program-specific objectives with broader agency goals and objectives, describe a clear definition of program success, and describe expected benefits to be produced by the program; (2) describe the program’s collective efforts, identify how planned actions contribute to achieving objectives, describe dependencies and linkages between program efforts, and prioritize program efforts to achieve objectives; and (3) describe processes for monitoring challenges (internal or external) and describe how the program will respond to challenges affecting ability to achieve objectives.

# Appendix II: Challenges Federal Agencies and Transportation Operators Face to Improving Resilience in the Transportation Sector

Federal and private sector stakeholders face a number of long-standing challenges to improve resilience to GPS interference in the transportation sector. In interviewing agency officials and external stakeholders, we identified several persistent challenges federal agencies and transportation owners and operators continue to face in improving positioning, navigation, and timing (PNT) resilience. We also identified similar challenges in federal reports conducted by and on behalf of agencies responsible for GPS management.<sup>1</sup>

## **Diverse PNT Needs**

Transportation owners and operators have a wide range of PNT needs that vary based on mode, location, and operating environment, which makes it difficult to identify a GPS backup or other resilience measures that could meet all users' needs. While all modes use GPS to enhance safety, owners and operators each apply PNT information differently and have different vulnerabilities based on their unique operating environments. For example, a PNT researcher told us that the maritime sector requires a GPS backup that has long-range capabilities and is compatible with ships and ports around the world; one industry stakeholder told us that a backup for aviation must work at high speeds and altitudes. PNT needs can even vary widely within modes. For example, an industry stakeholder told us that some transit and regional

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<sup>1</sup> We also reviewed reports non-federal bodies prepared on behalf of the agencies responsible for federal GPS management, such as the Homeland Security Operational Analysis Center, *Analyzing a More Resilient National Positioning, Navigation, and Timing Capability* (2021) and PNT Advisory Board, *Protect, Toughen, and Augment Global Positioning System for Users* (2018). The Department of Homeland Security (DHS) commissioned the Homeland Security Operational Analysis Center report, but DHS officials told us that DHS disagreed with some of the findings and the report does not represent DHS's official position.

railroads use transponders as a GPS backup, but transponders do not work well for larger freight railroads that travel longer distances.

In part because of these diverse PNT needs, there is no single backup for GPS that can meet all user needs, according to two federal reports.<sup>2</sup> The Department of Transportation (DOT) found that none of the 11 PNT technologies it tested could universally backup GPS. Instead, DOT found that the transportation sector needs diverse backup technologies. Similarly, the Department of Homeland Security (DHS) found that GPS backups should be specific to users' needs.<sup>3</sup> For example, one DOT official told us that most transportation users require high accuracy and reliability, which has limited the availability of alternatives.

### **Federal GPS Management**

Two of the federal reports we reviewed, as well as half of the federal officials and external stakeholders we interviewed, identified challenges with the federal management of GPS, such as conflicting or unclear roles and responsibilities and lack of agreement between agencies. These challenges, some of which are longstanding, have historically prevented action on some federal priorities.<sup>4</sup> For example, in 2018, the PNT Advisory Board—which is comprised of experts outside the government—found that the federal structure for managing GPS was not effective and resulted in a number of unexecuted mandates, including mandates related to improving resilience to GPS interference.<sup>5</sup> The Board found that despite twice announcing plans to meet a 2004 presidential directive to develop a complementary and backup system to GPS, DOT and DHS had not done so.<sup>6</sup> In 2013, we reported that DOT and DHS had not met

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<sup>2</sup> DHS, *Report on Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS)* (Apr. 8, 2020); Volpe Center, *Complementary PNT and GPS Backup Technologies Demonstration Report* (January 2021).

<sup>3</sup> DHS, *Report on PNT Backup and Complementary Capabilities to GPS* (2020).

<sup>4</sup> Some of these reports and issues are from prior to the issuance of Space Policy Directive 7 (SPD-7) in 2021, which reiterated and adjusted some roles and responsibilities for federal GPS management.

<sup>5</sup> PNT Advisory Board, *Protect, Toughen, and Augment Global Positioning System for Users* (September 2018).

<sup>6</sup> National Security Presidential Directive 39 (NSPD-39) (2004) required DOT and DHS to develop a backup system to GPS.

this requirement due to a lack of agreement on resilience measures and roles and responsibilities.<sup>7</sup>

Several federal officials and PNT researchers we interviewed also identified instances in which federal agencies responsible for managing GPS disagreed on measures for improving PNT resilience, which resulted in unmet requirements. For example, one federal official told us that the National Space-Based Positioning, Navigation, and Timing Executive Committee (EXCOM), the interagency body responsible for federal GPS management, did not publish the National Space-Based PNT Strategy, as required in its charter, because member agencies could not agree on the major points.<sup>8</sup> In 2020 and 2021, updated federal policies resulted in some changes to the federal management of GPS and PNT resilience, including agencies' roles and responsibilities. It is too soon to determine the extent to which those changes have addressed these long-standing management challenges.

### **Cost for Private Sector**

High costs that outweigh perceived benefits reduce the likelihood that transportation owners and operators will adopt more resilient technology. Ten of the federal reports we reviewed and one-third of federal officials and external stakeholders we spoke to found that cost for the private sector is a challenge to improving PNT resilience. For example, according to one report, fees for GPS backups could cost users thousands of

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<sup>7</sup> GAO, *GPS Disruptions: Efforts to Assess Risks to Critical Infrastructure and Coordinate Agency Actions Should be Enhanced*, [GAO-14-15](#) (Washington, D.C.: Nov. 6, 2013). We recommended that DOT and DHS establish a formal, written agreement that details how the agencies plan to address their shared responsibility for establishing a GPS backup outlined in NSPD-39. While DHS formed an interagency team in 2015 to develop a work plan to address GPS vulnerabilities, DHS and DOT did not execute a formal, written agreement to address their shared responsibility to develop and maintain backup position, navigation, and timing capabilities, as directed in NSPD-39. We closed the recommendation as not implemented in 2020. SPD-7 replaced NSPD-39 in January 2021 and eliminated the specific requirement for DOT and DHS to jointly develop and maintain a GPS backup. The National Defense Authorization Act for Fiscal Year 2017 included continued requirements for DOT and DHS to identify and plan for GPS backups. Pub. L. No. 114-328, § 1618, 130 Stat. 2000, 2595-2596 (2016). DHS officials told us that the National Timing Resilience and Security Act of 2018 required DOT to establish a backup timing system for GPS without reference to DHS and in their view, complicated coordination and roles DHS has in this area.

<sup>8</sup> EXCOM's original charter, signed in 2006, required EXCOM to develop a National Space-Based PNT Strategy to integrate individual agency space-based PNT goals into a comprehensive strategy that implemented the vision of the Space-Based PNT Policy and promotes consistency, cohesiveness, transparency and coordination among agencies.

dollars.<sup>9</sup> Transportation owners and operators are unlikely to take on these high costs unless they see clear benefits. According to four of the reports we reviewed and five of the federal and external stakeholders we interviewed, GPS users are unlikely to adopt costly resilience measures without a strong benefit. For example, DHS stated that unless GPS backup services are free, low-cost, or provide a benefit not found in GPS, there is no reason to assume users will adopt those services.<sup>10</sup>

In addition, transportation owners and operators' reluctance to invest in more expensive equipment may be because they are often unaware of the potential benefits of improved resilience and the risks of inaction. The PNT Advisory Board has found that transportation owners and operators are often unaware of their PNT vulnerabilities and the risks of depending on GPS. Additionally, one federal official told us that because many operators have not experienced GPS interference, they view it as an unlikely event, which limits incentive to pay for costly resilience measures. This lack of demand from users for more resilient PNT systems may further contribute to their relatively high costs, according to the PNT Advisory Board.<sup>11</sup>

### **Federal Resources**

Balancing the recognized need for GPS backups to support resilience with the demand on federal resources to develop and maintain these backups is a challenge. Over one-third of the federal officials and external stakeholders we interviewed, as well as five of the federal reports we reviewed, found that federal resource considerations have influenced federal efforts to maintain or develop GPS backups and achieve federal policy priorities. For instance, resource considerations factored into federal decisions to fully or partially decommission two legacy ground-based systems that supported maritime and aviation navigation and that could potentially backup GPS: (1) Coast Guard's Long-Range Navigation (LORAN) program, and (2) the Federal Aviation Administration's (FAA) Very High Frequency Omni-Directional Range (VOR) system.<sup>12</sup> Federal

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<sup>9</sup> DHS, *Report on PNT Backup and Complementary Capabilities to GPS* (2020).

<sup>10</sup> DHS, *Report on PNT Backup and Complementary Capabilities to GPS* (2020).

<sup>11</sup> PNT Advisory Board, *Protect, Toughen, and Augment Global Positioning System for Users* (2018).

<sup>12</sup> Prior to the introduction of GPS, LORAN-C was a navigation aid that used radio signals to help mariners and pilots navigate. VOR is an electronic system that provides positioning information for high and low altitude routes and airport approaches.

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reports and external stakeholders have found that, with some improvements, both systems could mitigate the effects of GPS interference for some applications.<sup>13</sup> However, as the maritime and aviation modes transitioned to technologies that rely on GPS, Coast Guard fully discontinued LORAN and FAA partially discontinued VOR, due in part to their determination that maintaining these legacy systems is not cost-effective.<sup>14</sup> Additionally, we previously identified resource constraints as a contributing factor to DOT and DHS making limited progress on a directive to establish a GPS backup.<sup>15</sup>

Additionally, in the view of DOT officials, DOT's primary challenge to fulfilling federal PNT resilience requirements has historically been a lack of resources.<sup>16</sup> For example, according to DOT officials, DOT did not receive funding to implement the resilience requirements in Executive Order 13905 (E.O. 13905) until March 2022, 2 years after the order was

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<sup>13</sup> Coast Guard began developing an enhanced system, known as eLORAN, but did not complete enhancements. In 2015 and later reiterated in a 2018 report, the PNT Advisory Board recommended implementing eLORAN as a backup timing capability. PNT Advisory Board, *Protect, Toughen, and Augment Global Positioning System for Users*. See also FAA, *Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications* (March 2004) and Volpe Center, *Benefit-Cost Assessment Refresh: The Use of eLORAN to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services* (Nov. 5, 2009).

<sup>14</sup> Pursuant to statutory requirements, Coast Guard terminated LORAN-C broadcasts in 2010. Department of Homeland Security Appropriations Act, 2010, Pub. L. No. 111-83, § 559, 123 Stat. 2142, 2180-2181 (2009). When explaining its decision to terminate LORAN-C broadcasts, Coast Guard stated that LORAN-C was not established as, or intended to be, a viable systemic backup for GPS. This determination was specific to LORAN-C and not to the planned eLORAN. Coast Guard, in coordination with DOT, found that sufficient alternative navigation aids existed to maintain transportation safety. DHS officials also told us that the declining user base of LORAN contributed to DHS's determination that it was not cost-effective to maintain. As part of its plan to transition to the Next Generation Air Transportation System and performance-based navigation, FAA plans to decommission approximately 34 percent of VORs in the U.S. by fiscal year 2030. FAA will maintain the remaining VORs as part of a minimum operation network to serve as a backup to GPS in the event of a disruption. See FAA Order 7400.2. As of October 2021, FAA had discontinued 113 VORs across the country.

<sup>15</sup> [GAO-14-15](#).

<sup>16</sup> As previously noted, DOT officials told us that DOT did not seek additional funding for PNT resilience efforts until recently.

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signed.<sup>17</sup> Officials told us that, as a result, DOT initially had to identify existing resources to begin implementing the order. DOT officials also told us that as of July 2022, the Office of the Assistant Secretary for Research and Technology (OST-R) had six full time staff members who work on PNT issues.<sup>18</sup> DOT officials also told us that FAA is the only operating administration that has significant funding and staff to work on PNT.

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<sup>17</sup> The Explanatory Statement accompanying the Consolidated Appropriations Act, 2022 (Pub. L. No. 117-103, 136 Stat. 49), signed in March 2022, directed funding for DOT to implement E.O. 13905, SPD-7, and recommendations from the Volpe Center's *Complementary PNT and GPS Backup Technologies Demonstration Report* (January 2021). H. Comm. Print 47-048 (Legislative Text and Explanatory Statement) accompanying Consolidated Appropriations Act, 2022, Book II at 2556 (2022).

<sup>18</sup> DOT officials told us that they also have six full-time staff members who work on PNT at the Volpe Center.

# Appendix III: Actions the Department of Transportation Has Taken in Response to Federal Requirements

**Table 5: Actions the Department of Transportation (DOT) Has Taken in Response to Federal Requirements Related to Management of Positioning, Navigation, and Timing (PNT) in the Transportation Sector**

Source	Requirement for DOT	Summary of Actions DOT has Taken in Response to Requirement
National Defense Authorization Act for Fiscal Year 2017, Pub. L. No. 114-328, § 1618, 130 Stat. 2000, 2595-2596 (2016)	In coordination with the Department of Defense (DOD) and Department of Homeland Security (DHS), study and report on backup and complementary PNT technologies.	DOT partnered with DHS to commission a study identifying backup and complementary PNT capabilities to GPS to address civil needs, including transportation. <sup>a</sup>
National Defense Authorization Act for Fiscal Year 2018, Pub. L. No. 115-91, § 1606, 131 Stat. 1283, 1725-1726 (2017)	In coordination with DOD and DHS, develop a plan for carrying out a backup GPS capability demonstration based on the results of the study conducted for the National Defense Authorization Act for Fiscal Year 2017.	DOT's Volpe Center conducted field demonstrations of 11 technologies that could offer complementary PNT service in the event of a GPS disruption. <sup>b</sup>
National Timing Resilience and Security Act of 2018, Pub. L. No. 115-282, § 514, 132 Stat. 4192, 4276-4279 (2018)	Develop a plan for the establishment of a land-based, resilient, and reliable alternative timing system.	DOT produced a roadmap to developing an implementation plan for an alternative timing system. <sup>c</sup> DOT's efforts to respond to the above requirements that involved identifying and testing complementary PNT technologies also contributed to meeting this requirement.
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(a)	Develop, in coordination with the Department of Commerce (Commerce), a PNT profile for the transportation sector	To gain a better understanding of the National Institute of Standards and Technology Foundational PNT Profile, DOT has three initial projects that will inform the development of a PNT profile for the transportation sector: maritime pilot program, PNT for Highly Automated Safety Systems, and Federal Aviation Administration (FAA) Timing Evaluation in Alaska.
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(b)	Refer to the PNT profiles when updating the Federal Radio navigation Plan	The 2021 Federal Radio navigation Plan describes the Foundational PNT Profile and states that the Department of Commerce is leading an effort in coordination with agencies, such as DOT, to develop sector-specific PNT profiles to help manage PNT-related risks in critical infrastructure sectors.
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(c)	In coordination with DHS, develop a plan to test the vulnerabilities of the transportation sector to PNT disruptions	DOT is coordinating with DHS on a vulnerability assessment and testing effort of three modes—aviation, rail, and maritime—to help understand the limitations, threats, and vulnerabilities of different PNT technologies as applied to these modes.



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<b>Source</b>	<b>Requirement for DOT</b>	<b>Summary of Actions DOT has Taken in Response to Requirement</b>
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(d)	In coordination with DHS, develop language for federal contracts to encourage use of additional PNT services	DOT is participating in DHS's efforts to develop contract language to encourage users and manufacturers to invest in resilience.
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(f)	In coordination with DHS, submit a report on the extent to which PNT profiles have been adopted in agency acquisitions and by critical infrastructure operators	Not applicable yet: DOT has not completed PNT profiles for the transportation sector, so we cannot report on their adoption by critical infrastructure operators.
Exec. Order No. 13905, 85 Fed. Reg. 9359 (Feb. 18, 2020): Sec. 4(g)	Develop a plan to engage with critical infrastructure owners or operators to evaluate responsible use of PNT services and develop a pilot program	DOT carried out a pilot program to test GPS jamming and spoofing affecting maritime vessels, which involved: conducting demonstrations of jamming and spoofing susceptibility on maritime GPS devices in a laboratory and field setting and testing a complementary PNT technology to assist with detection of GPS jamming and spoofing.  To engage stakeholders, DOT also hosted a workshop on jamming and spoofing in the maritime environment to increase public awareness of real-world incidents and technologies to improve PNT resilience.
William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, § 1611, 134 Stat. 3388, 4048-4049 (2021)	Consult with DOD about enabling civilian and commercial adoption of technologies and capabilities for resilient and survivable alternative PNT capabilities to complement GPS.	Through the maritime pilot program for E.O. 13905, DOT is proofing complementary PNT technologies on the Maritime Administration's Ready Reserve Force ships.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 5.(a)	Co-chair the National Space-Based PNT Executive Committee (EXCOM), which is the interagency body for providing and guiding whole-of-government interests in the provision of space-based PNT services, augmentations, and alternatives	The DOT Deputy Secretary serves as the co-chair of the EXCOM.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(b)(iv)	In cooperation with DOD and DHS, develop guidelines that facilitate DOD training, testing, demonstrations, and exercises	When DOD notifies of planned testing, FAA issues a Notice to Air Mission to notify pilots and controllers about areas potentially affected by GPS interference. In the event that the testing is affecting safety or operations, air traffic control can request a stop buzzer, and DOD will stop the intentional jamming.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(c)(iv)	In coordination with Commerce, the Department of State (State), DOD, and National Aeronautics and Space Administration (NASA), seek to protect the radio frequency spectrum used by GPS and its augmentations	DOT supports the Department's spectrum interest by participating in the National Telecommunications and Information Administration's Interdepartment Radio Advisory Committee and Policy and Plans Steering Group as well as working with EXCOM.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(c)(v)	In coordination with Commerce, DOD, DHS, and NASA, facilitate cooperation between the US government and the private sector as appropriate to identify mutually acceptable solutions that will preserve existing and evolving uses of space-based PNT services	DOT conducted an assessment to determine the maximum allowable power levels of nearby radiofrequencies tolerated by GPS receivers. <sup>d</sup> DOT has also developed as spectrum-monitoring capability in anticipation of the Ligado deployment.

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<b>Source</b>	<b>Requirement for DOT</b>	<b>Summary of Actions DOT has Taken in Response to Requirement</b>
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(i)	Lead responsibility for development of requirements for civil applications of space-based PNT	DOT uses established processes to develop and validate requirements for civil applications of GPS, including coordinating with DOD.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(ii)	Ensure, in coordination with DOD and DHS, performance monitoring of space-based PNT	DOT published the Civil Monitoring Performance Specification, which includes requirements for monitoring civil GPS service. DOT has ongoing work with the National Geospatial Intelligence Agency to implement signal-in-space performance monitoring. FAA also continuously monitors GPS Wide Area Augmentation System performance.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(iii)	Facilitate, in coordination with State, international participation in the development of civil transportation applications using U.S. space-based PNT	DOT participates in various international efforts, such as forums and working groups, to collaborate on international global navigation satellite system standards and other topics related to the development of civil transportation applications using space-based PNT.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(iv)	In coordination with State and DOD, ensure that international transportation initiatives consider the dual-use nature of space-based PNT services	DOT participates in international efforts, including forums and organizations related to transportation, and promotes awareness of the dual-use risks inherent in open information sharing of space-based PNT services.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(v)	Ensure, in coordination with DOD, that public safety service applications based on U.S. space-based PNT services meet or exceed internationally recognized standards	DOT participates in international efforts, including forums and organizations, to ensure that public safety service applications based on U.S. space-based PNT services meet or exceed internationally recognized standards.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(vi)	Promote the responsible use of US and foreign civil space-based PNT services and capabilities for transportation safety as directed in E.O. 13905	DOT has several initiatives to implement E.O. 13905 and promote PNT resilience, including the maritime pilot program on jamming and spoofing impacting maritime vessels, vulnerability assessment and testing for several transportation modes, and efforts related to PNT resilience for highly automated systems.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(vii)	Represent the civil agencies in the development, acquisition, management, and operations of GPS and its augmentations	DOT provides liaisons to the U.S. Space Force to represent DOT and the civil agencies in GPS development and management, participates in GPS contract planning, and supports the GPS enterprise acquisition effort at Space Systems Command and GPS operations at Space Operations Command.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(viii)	In coordination with DOD and DHS, implement Federal and facilitate State, local and commercial capabilities to monitor, identify, locate, and attribute space-based PNT service disruption and manipulations	DOT currently uses a manual process, largely dependent on user reports, to detect GPS interference affecting civil users. In 2022, DOT received funding to develop an interference detection and monitoring capability and will collaborate with DOD and DHS on this effort. <sup>e</sup>
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(ix)	Ensure the earliest operational availability for modernized civil signals and services on GPS and its augmentations in coordination with DOD	DOT has ongoing work with an interagency team, known as the Civil Signal Operational Capability Integrated Product Team, to further efforts toward initial and final operational capability of new GPS civil signals.

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<b>Source</b>	<b>Requirement for DOT</b>	<b>Summary of Actions DOT has Taken in Response to Requirement</b>
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(x)	In coordination with DOD, assess and assist in the international acceptance of using the military PNT services of GPS for operations in civil airspace	FAA interacts with the International Civil Aviation Organization and Department of State to promote GPS and foster the continued acceptance of civil and military GPS for aviation safety.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(xi)	Facilitate international coordination for the development of monitoring standards for space-based PNT services	DOT has a leadership role in the International Committee on GNSS to develop global navigation satellite systems performance standards and works with other international organizations to establish and update monitoring standards.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(xii)	Maintain awareness of the risks and potential benefits associated with the use of foreign space-based PNT services	DOT performs analyses and contributes to the advancement of harmonization and standardization of global navigation satellite systems with other countries through various working groups and domestic and international forums.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(d)(xiii)	In coordination with DOD and DHS, develop and validate requirements and a funding strategy to implement data and signal authentication of civil GPS and wide area augmentations	In 2022, DOT received funding to conduct research that will result in the development and validation of requirements for a data and signal authentication capability for civil GPS. <sup>e</sup> DOT will leverage ongoing signal authentication research efforts and work with DHS on a strategy to implement data and signal authentication of civil GPS. FAA signed a memorandum of understanding with the Air Force Research Laboratory in part to leverage signal authentication capabilities planned on the Navigation Test Satellite-3, which is planned for launch in 2023.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(e)(iii)(B)	In coordination with DHS, DOD, and Commerce, develop procedures to notify the civil sectors and federal, state, local, territorial, and tribal agencies when space-based services have anticipated disruptions	FAA issues Notices to Air Missions to notify aviation users of GPS disruptions. DOT also receives notifications from DHS, including U.S. Coast Guard Navigation Center (NAVCEN), on events affecting critical infrastructure and can escalate and disseminate to civil sectors as needed.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(e)(iv)	In coordination with DHS, DOD, and Commerce, develop and maintain capabilities and procedures for civil contingency responses to ensure continuity of operations in the event of GPS disruptions	DOT participates in an interagency information-sharing process to exercise notification for civil contingency responses and ensure continuity of operations in the event of a GPS disruption.
Memorandum on Space Policy Directive 7 (SPD-7) (2021): Sec. 7.(g)(ii)	In coordination with NASA, DOD, and Commerce, develop requirements for GPS support of space operations and science in higher orbits	According to DOT officials, DOT has supported NASA with its development of requirements for GPS use in space.

Source: GAO analysis of Department of Transportation information. | GAO-23-105335

<sup>e</sup>DHS, *Report on Positioning, Navigation, and Timing (PNT) Backup and Complementary Capabilities to the Global Positioning System (GPS)* (Apr. 8 2020); Homeland Security and Operational Analysis Center, *Analyzing a More Resilient National Positioning, Navigation, and Timing Capability* (2021).

<sup>b</sup>Volpe Center, *Complementary PNT and GPS Backup Technologies Demonstration Report* (January 2021).

<sup>d</sup>DOT, *National Timing Resilience and Security Act Roadmap to Implementation* (January 2021). In DOT's fiscal year 2022 budget request, DOT requested that this requirement be repealed. Based on

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**Appendix III: Actions the Department of  
Transportation Has Taken in Response to  
Federal Requirements**

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its prior work, DOT reported that (1) no single solution for the provision of back-up or complementary PNT services can meet the diversity of critical infrastructure application requirements, and (2) it would be inefficient, anti-competitive, and potentially harmful to government to procure or otherwise fund a specific solution for non-federal users. According to DOT officials, the provision has not been repealed to date. See Consolidated Appropriations Act, 2022, Pub. L. No. 117-103, 136 Stat. 49 (2022).

<sup>d</sup>DOT, *Global Positioning System (GPS) Adjacent Band Compatibility Assessment* (April 2018).

<sup>e</sup>Consolidated Appropriations Act, 2022 (Pub. L. No. 117-103, 136 Stat. 49).

# Appendix IV: Comments from the Department of Transportation



U.S. Department of  
Transportation

Assistant Secretary  
for Administration

1200 New Jersey Avenue, S.E.  
Washington, DC 20590

Office of the Secretary  
of Transportation

December 1, 2022

Ms. Heather Krause  
Director, Physical Infrastructure  
U.S. Government Accountability Office (GAO)  
441 G Street NW  
Washington, DC 20548

Dear Ms. Krause,

The U.S. Department of Transportation (DOT) leads the Federal role of coordinating civil sector Positioning, Navigation, and Timing (PNT) requirements and represents the civil (non-defense) Departments and Agencies in the development, acquisition, management, and operations of the Global Positioning System (GPS) in coordination with the Department of Defense (DoD) per Presidential Space Policy Directive 7, "U.S. Space-Based PNT Policy." Within DOT, the Office of the Assistant Secretary for Research and Technology plays a critical role in the implementation of Executive Order 13905, "Strengthening National Resilience Through Responsible Use of PNT Services," by conducting PNT vulnerability assessment and testing to raise awareness of the extent to which the Transportation Systems Sector depends on PNT services; identifying operational approaches to withstand disruption or manipulation of those services; and engaging the transportation community to promote the responsible use of PNT services.

To improve PNT resilience, DOT's PNT resiliency priorities are focused on activities to:

- Protect the Spectrum: Detect and Mitigate Interference
- Toughen Receivers: GPS Cybersecurity and GPS Signal/Data Authentication
- Augment: Adopt Use of Appropriate Complementary PNT Technologies

DOT will continue to focus on improving efforts to identify interference incidents and strengthen resilience, and DOT has entered into a partnership with the Defense Innovation Unit to begin implementation of an automated GPS interference detection capability. A key metric with respect to GPS interference detection and mitigation is the amount of time it takes to detect and locate GPS interference and remove the source. Reducing this duration improves PNT resiliency.

Upon review of the draft report, "DOT Could Improve Efforts to Identify Interference Incidents and Strengthen Resilience," DOT concurs with GAO's two recommendations to DOT: (1) document its incident identification process, including identifying controls, to obtain complete and accurate information; and (2) develop a strategic approach to PNT resilience that fully aligns with key standards for program management.

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**Appendix IV: Comments from the Department  
of Transportation**

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We appreciate the opportunity to respond to the GAO draft report. We will provide a more detailed response to each recommendation within 180 days of the final report's issuance. Please contact Gary Middleton, Director, Audit Relations and Program Improvement, at 202-366-6512 with any questions or if you would like to obtain additional details.

Sincerely,

Philip A. McNamara  
Assistant Secretary for Administration

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## Text of Appendix IV: Comments from the Department of Transportation

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Director, Physical Infrastructure

U.S. Government Accountability Office (GAO) 441 G Street NW

Washington, DC 20548

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Philip A. McNamara

Assistant Secretary for Administration



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## Appendix V: GAO Contact and Staff Acknowledgments

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### GAO Contact

Heather Krause, 202-512-2834, [KrauseH@gao.gov](mailto:KrauseH@gao.gov)

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### Staff Acknowledgments

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