Transportation Systems Sector

Use of Positioning, Navigation and Timing (PNT) Services

These comments are based upon public and private assertions made by representatives of this Critical Infrastructure/Key Resource (CI/KR) sector and PNT subject matter experts that have examined such issues. Some members of CI/KR sectors might not provide public comment out of a desire to avoid disclosing vulnerabilities and/or proprietary information. Therefore, the RNT Foundation is providing this response for the public record "on their behalf." See explanatory notes at the end of this document.

GPS PNT services have been integrated into virtually every technology and are a critical to nearly every facet of life in America. As such, their impact on one sector very much impacts another. For example, the transportation and communications sectors both rely heavily on GPS, and all sectors rely heavily on transportation and communications. The comments in this response try to address only the ways in which GPS/ PNT services are uniquely used by this sector.

These comments have been structured to respond as directly as possible to the questions posted in the Federal Register (***bold italics*** below).

Sidebar: The Department of Transportation has performed and participated in numerous studies on the requirement for resilient PNT in the transportation sector. One of the inaugural efforts was a landmark report in 2001 by the Volpe Transportation Systems Center recommending a complementary system for GPS.[1] This was followed by many other studies, including Volpe's 2009 *Benefit-Cost Assessment Refresh, The Use of eLORAN to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services.*[2] It is not the intent of this submission to reiterate all this material. Rather, we wish to ensure that those perusing the public record in this docket are able to obtain a general understanding of the many ways PNT is used and required by the Transportation Systems Sector.

(a) A brief description of your application(s) of positioning, navigation, and timing services;

1. **General Location & navigation**
   A study commissioned by Google in 2013 estimated that geospatial services helped the US economy generate $1.6 trillion/year and saved the economy another $1.4 trillion/year.[3]

   a. **Routing –** GPS services enable previously impossible efficiencies in time, fuel, and overall transportation costs. The 2013 Google study calculated that that annual worldwide travel time is reduced by 1.1 billion hours and global fuel consumption reduced by 1 billion gallons.[4]

   b. **Tracking** – Untold additional economies per year are gained by the ability to track the location, speed, and overall progress of vehicles, people, and packages. Foremost, but

[1] http://www.navcen.uscg.gov/pdf/vulnerability_assess_2001.pdf
[2] http://rntfnd.org/wp-content/uploads/Benefit-Cost-of-eLoran-Volpe-Center-2009.pdf
[3]https://www.bcgperspectives.com/content/interviews/digital_economy_technology_potere_david_geospatial_growth_engine/
[4] http://google-latlong.blogspot.com/2013/01/mapping-creates-jobs-and-drives-global.html?m=1

perhaps the least quantifiable, are operational/human efficiencies gained through vastly improved coordination of operations and use of time (for example, because the arrival time of supplies is reliably forecast and updated, other tasks in a building project can be more efficiently scheduled). Improvements in inventory control, including reduced shrinkage and automated accounting, have also been significant.

2. Transportation Modes

a. **Rail –** Location information is essential for development and implementation of congressionally mandated Positive Train Control (PTC). The Federal Railroad Administration has cited GPS and location as an integral part of such systems.[5]

b. **Maritime –**

i. **Recreational Vessels –** GPS-based electronic navigation and charting is easily available to the 12,000,000$^+$ recreational vessels in the US via mobile technology. For less than the cost of a tank of fuel, in many cases, vessel owners can purchase a dedicated maritime navigation and charting system.

ii. **Commercial Vessels** - Approximately 10,000 commercial vessels are registered in the United States and thousands more from around the world make port calls each year transporting bulk cargos (many of which are hazardous), and containers. PNT (GPS) is used by almost every electronic system on the bridges of these vessels. Impacted systems include gyro compass, radar, navigation, charting, and AIS. It is also used in systems for vessel/helideck stabilization.[6] See our comments on the Energy Sector for information about commercial drilling vessels that use dynamic positioning.

iii. **Fishing Vessels** – The approximately 20,000 commercial fishing vessels in the US use PNT for geolocation and are concerned more with precision repeatability than absolute (latitude/longitude) accuracy. For example, lobstermen and crabbers would use Loran lines to mark their pot locations and would be able to return to them unfailingly.

iv. **Shore support to the Marine Transportations System (MTS)** - GPS/PNT is also essential to many systems ashore that support the MTS. These include vessel traffic services, maritime surveillance, and cranes at container ports. The primary maritime anti-collision and maritime domain awareness system, AIS, is completely dependent upon GPS timing and location. Unfortunately, AIS equipment will continue to operate in the absence of a GPS signal, but will not provide correct positioning information, which could be hazardously misleading.

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[5] Federal Railroad Administration, Washington, DC (2002). "Railroad Research and Development Program: Train Control." Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations. Document no. FRA/RDV-02/02. p. 4-47

[6] http://rntfnd.org/wp-content/uploads/GNSS-Maritime-GLA.pdf

Note that the US Coast Guard regards GPS vulnerability as a cybersecurity problem for all components of the maritime domain.[7]

c. **Surface –**

i. **Operation of Traffic Lights/Signals**

- Many traffic light synchronization systems that minimize the number of stops vehicles must make on major roadways use GPS as a reference clock.
- Traffic light preemption systems used by emergency vehicles and city bus systems use GPS as a location and direction-of-travel sensor. These systems signal traffic lights ahead of the vehicle to turn green just prior to its arrival.

ii. **Traffic Awareness & Management** – GPS location is an essential component of systems that support individual drivers and traffic management authorities understanding system traffic flow as well as problems in specific areas.

iii. **Vehicle Navigation** – Because GPS has been incorporated into mobile devices, it is used by every class of vehicle in every possible application.

d. **Aviation –**

i. **Air Traffic Systems** – All air traffic control and coordination systems use both time and location. A common time reference is required to coordinate surveillance and operations over broad areas, and to ensure that forensic efforts are able to correctly merge sensor feeds for mishap analysis. Systems such as ADS-B require synchronized precise time to as little as 30 nanoseconds.[8]

ii. **Navigation Aids** – While aviation navigation systems such as VOR, DME, and ILS provide positioning and navigation services, they are also consumers of time. As the number of these systems continue to be reduced in the transition to the "NextGen" air traffic system, the need for precise synchronized time will greatly increase. Much of the original business case for NextGen was based on the FAA being able to shut down a large fraction of its ground-based navaids (i.e., VOREs, secondary radars, etc.). Because there is no national GPS backup capability, the FAA's current plan is to retain far more of this expensive ground-based navaid infrastructure, significantly reducing the cost savings on which NextGen was premised as a sound investment. A low-cost, national complement to GPS

[7] http://rntfnd.org/2015/02/11/gps-disruption-halts-ports-endangers-ships-us-coast-guard/

[8] ADS-B has the following timing requirements:

- 50 nsec (relative time) at Radio Stations for validation of ADS-B via Time Difference of Arrival (TDOA) measurements
- 30 nsec (relative time) at Radio Stations for Multilateration (ADS-B Backup)
- 500 nsec (within UTC) at Radio Stations for ADS-B service
- 2 msec (within UTC) Network Time at indoor locations (some locations do not accommodate a GPS antenna to a rooftop location)

("complement") would enable a return to the original plans, restoring the original business case for NextGen.

iii. **Aircraft** – There are approximately 220,000 General Aviation, 14,000 military aircraft, and over 7,000 commercial air carrier aircraft in the United States. These aircraft use GPS for navigation and to support a number of location-based services (facilities and frequency look-up, emergency diversion planning, weather services, etc.). The reliance on GPS for navigation varies between the three aircraft fleets, with General Aviation having the highest need for an inexpensive alternative and no ability to use military grade technology.
Commercial carriers do not generally use GPS for navigation, but do use GPS to support location-based services in the cockpit, as mentioned earlier. Some passenger cabin services are supported by the GPS signal as well. Commercial carrier passenger and cargo aircraft are the most dependent upon the smooth functioning of the National Airspace System and its supporting technologies, many of which rely in various ways on GPS time.

(b) the positioning, navigation, and/or timing performance required for a complementary PNT capability to support operations during a disruption of GPS that could last for longer than a day,

To qualify as a "complementary" system, a new PNT capability would need to:

1. **Provide very wide area, precise, wireless location and timing services.** The timing signal would need to be synchronized with UTC (and therefore GPS, when in it is in operation) and location information would have to correspond to that obtained from GPS as closely as possible.
2. **Have features and/or capabilities not available with GPS.** Without such it would be a "duplicate" or "redundant" service, vice "complementary." Desired features for special-purpose users, such as First Responders and the military, include a signal that is usable under foliage, underground (i.e., garages), indoors and that has a robust, security-capable, data channel for differential corrections and other information.
3. **Likely remain functioning in situations when GPS is disrupted.** The complementary system should have different signal characteristics, and therefore different failure modes, than GPS. These include a signal that is terrestrial based, high power and in a frequency band far distant from that of GPS.

The navigation accuracy and timing requirements for each mode of transportation and each use vary widely. For example:

> Aviation non-precision VOR approaches advertise an accuracy of $\pm$ 1.4° (this is $\pm$119 meters when the aircraft is three miles away from the VOR, which may or may not be anywhere near the airport). By contrast, the International Maritime Organization radio-navigation requirement for harbor entrance is an accuracy of 10 meters[9].

[9] http://www.imo.org/KnowledgeCentre/IndexofIMOResolutions/Documents/A%20-%20Assembly/1046%2827%29.pdf

The timing accuracy needed for ADS-B to properly function is 30 nanoseconds, while that for the maritime AIS system is approximately 300 microseconds for shipboard units[10] and 52 microseconds for base stations.[11]

The PNT performance needs of all aspects of the transportation systems sector are well known to the Department of Transportation. We recommend that DOT publish and maintain an index that would both enable government decision makers and help empower the private sector to support these needs.

(c) availability and coverage area required for a complementary PNT capability,

Availability. Any system intended to complement GPS should have the same availability as the GPS system.

Coverage. As illustrated in the graphic at the end of these comments, a multi-layer model provides the best PNT resiliency. eLoran complements GPS/GNSS' global coverage, provides continental PNT coverage, and complements or enables local PNT coverage.

Supporting US transportation systems will require coverage across the land mass of the United States and seaward to the extent of the Exclusive Economic Zone.

(d) willingness to equip with an eLoran receiver to reduce or prevent operational and/or economic consequences from a GPS disruption,

Note: Our interaction with receiver manufacturers causes us to believe this question to be irrelevant except for the first few years of an eLoran system's operation. Once an eLoran system is in operation and receivers are in wide production, the size, weight, power, and cost (SWAP-C) of the receivers will decrease dramatically. We expect most commercial grade navigation receivers to be "multi-mode", having the capability to receive GPS/GNSS and Loran/eLoran. Many receivers might also include inertial, gyro, CSAC, and/or barometric altimeters. Thus it will not be a matter of a user's "willingness to equip," but rather that the market will be automatically equipping the user. As one manufacturer expressed it: "Except for niche applications, building GPS-only receivers wouldn't make sense."

General - The willingness of any user within the transportation sector to be an early adopter of the technology will depend upon the price point of the equipment, as well as regulatory and market pressures.

Maritime – Loran-C was very popular with recreational and commercial fishermen because of its very high precision repeatability. Commercial maritime, especially foreign flagged cargo and bulk operators, have very thin margins and generally would not be early adopters without internationally mandated carriage requirements (which have been proposed by IALA and IMO).

[10] IEC 61108-1
[11] IEC 62320-1:2015

Aviation –

Air Traffic Systems – Air traffic systems such as ADS-B and NextGen's DME/DME navigation solution(s) would quickly adopt eLoran as a time source to complement GPS in lieu of acquiring thousands of expensive oscillators and clocks.

We understand that the FAA's Next Generation Air Traffic System will use approximately 2,000 VOR and DME transmitting stations to complement GPS to provide aviation "Assured PNT." The FAA should be willing to adopt eLoran as quickly for assured PNT thereby avoiding the high cost of maintaining 2,000 geographically dispersed transmitting stations.

General Aviation – General aviation users are much more open to new technologies and Loran-C was fairly widely used by this group prior to its termination in 2010. Because the US originally announced that Loran-C would be terminated at the end of December 2000, manufacturers and users avoided investing in new receivers.

Commercial Air Carriers – This group will probably be "last adopters" because of the cost and difficulty (both of which, in the absence of real data, are feared to be much greater than is likely) of incorporating a new technology.

(e) current and planned availability of e-Loran capable user equipment,

Loran-C and/or Chayka user equipment is now produced by the governments of China and Russia for internal consumption and use with their national systems. Outside of those countries, Loran-C and eLoran receivers are produced in limited quantities, on demand. RNT Foundation discussions with several large receiver manufacturers have indicated that they would readily pursue development of integrated receivers that include eLoran capability if there were Government support for the provision of eLoran service. The estimated economic order quantity for these vendors is approximately 100,000, although the number of units depends upon the market sector served. Also, once this level of production has been achieved, the size of receivers will undoubtedly be reduced to be compatible with many mobile devices, and the price per unit will drop dramatically (as was the case with GPS technology).

The US Army has extensive information on this as a result of a recent RFI for 50,000 eLoran receivers.

(f) other non-eLoran PNT technologies or operational procedures, currently available or planned, that could be used during a disruption of GPS for longer than a day.

Sidebar: In 2011, Mr. James Caverly, at that time working for the DHS Office of Infrastructure Protection, reported on the department's "**GPS Critical Infrastructure Timing Study: Usage/Loss Impacts/Backups/Mitigation.**" This report has never been made public, to our knowledge. A publicly released presentation based on the report provides information about requirements and backup systems for all critical infrastructure sectors and cites the situation generally as worsening.[12]

Navigation: During a GPS outage all transportation systems will –

- **Slow down significantly,**
- **Be much more mishap prone,**
- **Deliver Hazardous Misleading Information,**
- **Accidents will increase, and**
- **Have much less capacity**.

Non-GPS navigation technologies and operational procedures exist for all transportation modes. However, these older technologies and procedures are unable to support the same speed and volume of service as is possible with GPS. Additionally, many of the alternatives may not be readily available (e.g., drivers may not have maps and sufficient maps may not be readily available for sale to all drivers who need them). Also, many people may no longer be skilled in the use of older technologies and procedures.

Timing: No alternate timing system exists for shipboard AIS and many other transportation applications that require wireless, synchronized time. Expensive oscillators and atomic clocks could probably support shore-based maritime systems and terrestrial air traffic systems, although these are not typically now in place, and would be difficult and expensive to obtain and maintain.

The 2009 Volpe Cost-Benefit Study for eLoran limited its quantitative analysis of benefits to those accruing to only the maritime logistics and telecommunications sector. It found that, just for those two sectors, the benefits of establishing an eLoran system exceeded costs by $1.22B.[13] The study asserts, and we agree, that were all the benefits of establishing such a system to be totaled, the amount would be much higher.

Explanatory Notes:

1. The Resilient Navigation and Timing Foundation (RNTF):

RNTF is a scientific and educational 501(c)3 non-profit dedicated to helping protect critical infrastructure through (a) stronger laws and better enforcement against jamming and spoofing of GNSS signals, and (b) encouraging strong, difficult-to-disrupt terrestrial systems to complement and provide additional resilience for GNSS.

Our corporate membership includes providers of a broad spectrum of PNT services from development of GPS satellites, to local and indoor positioning systems, and wide area low frequency systems, and some of the world's leading navigation associations. Individual members are concerned citizens and PNT professionals from academia, industry and government.

[12] http://rntfnd.org/wp-content/uploads/James-Caverly-DHS-GPS-PNTTimingStudy-SpaceWeather4-27-111.pdf
[13] http://rntfnd.org/wp-content/uploads/Benefit-Cost-of-eLoran-Volpe-Center-2009.pdf

2. The Reason We Are Providing These Comments:

Our nation's increasing reliance on GPS location and timing information for a very broad spectrum of technologies represents, in the words of Dr. Brad Parkinson, "… a single point of failure for much of America…" We believe that national effort to provide and encourage adoption of diverse sources of location and timing information, provided by both federal and private entities, are essential to our national and economic security.

We believe responses to this request for comment may be limited by individual companies' reluctance to air their vulnerabilities or the perception that they would be revealing proprietary information.

3. How These Comments Were Developed:

The information provided was developed in coordination with our members who have had extensive interaction with the critical infrastructure sector being addressed. Information available in the media, professional discussion sites and other "open sources" has also been included.

4. eLoran:

The request for comment mentions in several places a possible "eLoran" system. Such technology is not generally known in the United States, even though it was developed here.

For purposes of this response, we presume that the eLoran system mentioned is similar to the one in operation in the United Kingdom as recently described in a paper presented to the Institute of Navigation[14]. With appropriate ASF corrections, this system's accuracy has been measured at less than 25 feet for location and less than 50 nanoseconds for timing. While we understand that the Dutch have improved on these results, the underlying system is still eLoran. While most technologists agree that much better performance is possible with further system development, our presumption is that the system the government refers to is the one described in the referenced paper.

5. The Importance of Quickly Implementing a Complementary System for GPS

We are unable to improve upon the 2004 Presidential National Security Directive 39 issued by President Bush and affirmed by President Obama that identified GPS as essential to our national economy and national security, and mandated acquisition of a "back-up" system – though we agree that a more appropriate descriptor would be "complementary" system.

Since 2004 threats to GPS have increased, as have the number of disruptive incidents per day. The threats range from fleeting local disruptions such as might be caused by a private citizen passing by with an illegal "Personal Privacy Device," to a global outage resulting from malicious intervention or simple human error.

GPS is currently being modernized and made more resilient. It is also being joined by other modern systems, including Galileo (Europe), Beidou (China), QZSS (Japan), INRNSS (India).

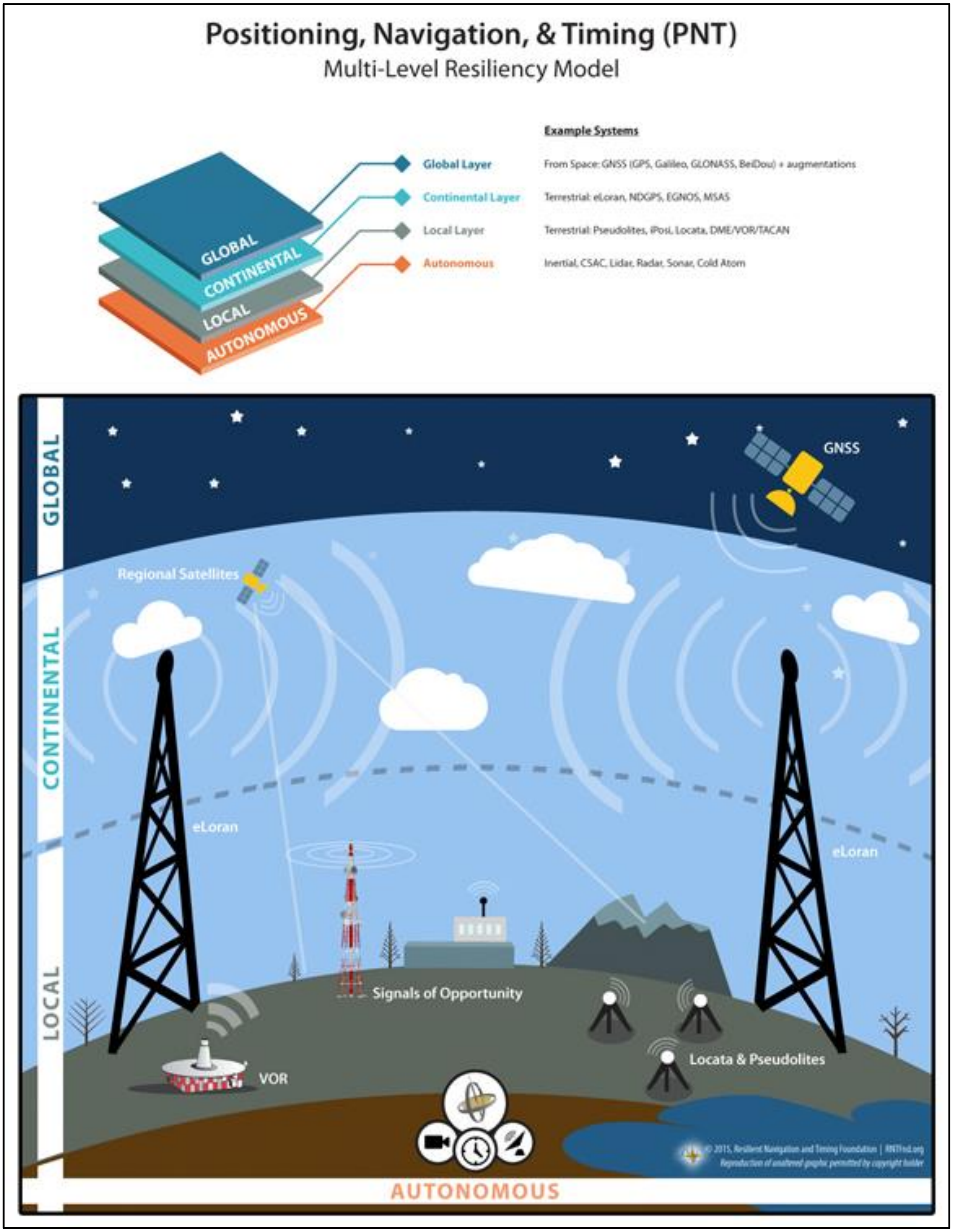
[14] http://rntfnd.org/wp-content/uploads/2015-ION-ITM-Offermans-eLoran-IOC-in-UK-final-4Feb.pdf

GLONASS (Russia) is being upgraded over a longer time period to include digitally modulated signals. These have certain resilience features for GPS. These are all positive developments that should be continued in order to improve the overall resilience of our global PNT architecture.

In April of last year, GLONASS, the Russian satellite navigation and timing system, experienced two unannounced outages, one of which lasted for eleven hours. If this were to happen to the GPS constellation, unless there were complementary systems, such as other GNSS or eLoran, that users had adopted and which would prevent PNT service disruption, the impact to our critical infrastructure and economy would be widespread and serious.

The larger question, beyond those that the Department of Transportation has posed in the Federal Register, is:

What would happen to our CI/KR, to our nation, and to the daily lives of its citizens, should there be a 24-hour disruption of GPS for any reason?


Positioning, Navigation, & Timing (PNT)
Multi-Level Resiliency Model
Example Systems
Global Layer
From Space: GNSS (GPS, Galileo, GLONASS, BeiDou) + augmentations
Continental Layer
Terrestrial: eLoran, NDGPS, EGNOS, MSAS
Local Layer
Terrestrial: Pseudolites, iPosi, Locata, DME/VOR/TACAN
Autonomous
Inertial, CSAC, Lidar, Radar, Sonar, Cold Atom
GLOBAL
CONTINENTAL
LOCAL
AUTONOMOUS
GNSS
Regional Satellites
eLoran
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