Unmanned Systems:
Without PNT, They're Not Going Anywhere

Before unmanned systems can realize their full potential, we must know what PNT systems will be available across the nation and how reliable they'll be.

DANA A. GOWARD

A small pilotless craft races through the surf and delivers flotation to a swimmer in trouble. Drones inspect and spray cleaning fluid on high tension electrical lines more quickly and safely than a conventional helicopter. Driverless trucks travel farther and safer than when a human is behind the wheel.

Unmanned systems have nearly limitless potential to benefit society. But they must know where and when they are.

It's clear unmanned systems have created a new paradigm. While they support existing, sometimes ancient, modes of transportation and functions, remotely controlled and autonomous systems demand new approaches to ensure safe, secure and efficient operations.

One of the most significant is their need for robust and resilient positioning, navigation and timing (PNT).

For Platforms

At the platform level this means navigation (or PVT - position, velocity, time) solutions with high availability and the required accuracy.

As with any set of applications, specific requirements vary. For example, an unmanned ship transiting the Pacific to meet a human pilot within two miles of a harbor entrance buoy will have far different PVT requirements than an autonomous crane picking up and stacking shipping containers at a busy port.

In most instances, though, creating and maintaining confidence in platform safety and reliability will require multiple and diverse sources of PNT.

Professor Todd Humphreys at the University of Texas Radionavigation Laboratory has described this as "deep layered navigation." In a paper on PVT for urban air mobility, he postulated combining carrier-phase-differential GNSS with terrestrial radionavigation systems and an inertial sensor as a basic requirement. Other sources and sensors would be added as needed. One example might be a highly precise local beacon to ensure pinpoint landings.

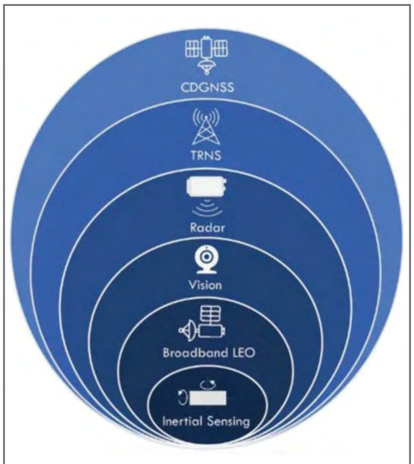
"**The future of unmanned systems** in the U.S. is inextricably linked to the future of PNT."

Transportation Systems and Infrastructure

A more compelling and complex question than platform PNT needs centers around PNT requirements for a national transport system that can safely and efficiently incorporate a large number of unmanned platforms. Here's a look at the necessary pieces:

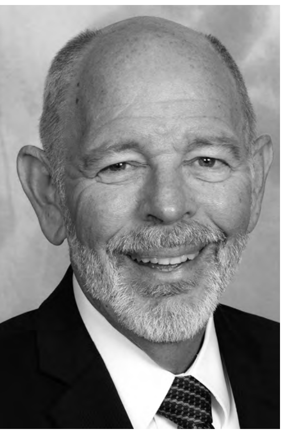
Common Operational Pictures (COP): Reliable, trustworthy PNT is essential for knowing where (and when) platforms are and having an idea where they are going. This situational awareness, or common operational picture (COP), is indispensable tech infrastructure for safe, secure and efficient transportation.

When thinking about COPs, most people visualize an air traffic control display with bright icons of aircraft moving about a screen, yet they exist to some degree in every mode of transportation. Maritime platforms in harbors and near the coast are tracked by AIS and radar, and they are tracked across the



Source: Professor Todd Humphreys, University of Texas.

FIGURE 1 Diagram of deep layered navigation. Overlapping layers of navigation to provide a PVT solution with high availability even when some of the layers are not available.



Dana A. Goward is President of the nonprofit Resilient Navigation and Timing Foundation, a public benefit charity advocating for policies and systems to protect GPS satellites, signals and users. He is a member of the President's National Space-Based Advisory Board, and has received multiple international awards for his leadership and advocacy for resilient PNT architectures. Goward is a retired Coast Guard officer and helicopter pilot. In 2013, he retired from the federal Senior Executive Service having served as the maritime navigation authority for the United States.

globe by satellite. Railroads constantly monitor train activity using GPS and track sensors and systems like Positive Train Control. Highway departments use in-road and overhead sensors as well as video and digital tools to monitor traffic. And fleet tracking systems and apps like Google Maps and Waze provide tailored transportation COPs for companies and individuals.

COPs can inform and directly benefit system participants. Think aircraft and ships avoiding collisions, and drivers getting traffic-informed routing from Waze or Google Maps. Informed actions by individual users can help make the overall transportation system safer and more efficient.

From a transportation system authority's point of view, a COP can enable:

- Monitoring the environment (including weather), issuing warnings, perhaps modifying traffic flow.
- Emergency responses, not only by ensuring they are quickly initiated, but also through blue force tracking, optimal response routing, and other applications.
- Optimizing traffic flow to the extent tools allow.
- Understanding patterns and performing other analyses to improve system performance and planning.
- Identification of anomalous behavior and threats.

In a world where the highest profile use of unmanned systems is to attack adversaries with inexpensive, easy to obtain and operate drones, this last function is especially critical. Being able to identify friend or foe is already crucial for system and user security in conflict zones.

That's equally true for routine peacetime civil/commercial operations. Aside from security considerations, being able to do this visibly and reliably is essential for gaining public trust and confidence in unmanned systems. Without such trust, broad implementation of unmanned systems will face innumerable obstacles and delays.

Communications: Timing, the "t" of PNT, underlies virtually every communications technology. Time Division Multiple Access (TDMA) enables multiplexing for land mobile radios—using the same frequency for many simultaneous conversations. Time Division Duplexing synchronizes base stations for cell networks. Even fiber-based internet relies on timing synchronization and time of day to record past events and properly sequence future ones.

If operators can't communicate with their platforms, the platforms can't communicate with each other and authorities, and there is no system. Instead, you merely have a chaotic mix of activity that will result in any number of inefficiencies and casualties.

> **"The extent and nature of national PNT** infrastructure will have a profound effect on how quickly the unmanned industry is able to implement and proliferate systems."

IT and System Controls: Time and timing are also essential for every IT system and many control applications. These range from complex and sophisticated algorithms guiding computational networks to systems as straightforward as traffic lights sequenced to allow smooth flow at the speed limit through multiple intersections.

Who Does What?

The future of unmanned systems in the U.S. is inextricably linked to the future of PNT. Before unmanned systems can truly progress at scale, we all must know what PNT systems will be available across the nation, how reliable they will be, and how easily they can be accessed. We need to clarify the roles of industry and government, or "who does what." These questions must be addressed soon to allow the unmanned industry to grow domestically.

The U.S. government has provided navigation infrastructure to underpin national security and foster economic activity since the earliest days of the republic. Congress' first public works legislation was the Lighthouse Act of 1789. A sailing ship and a lighthouse remain on the Commerce Department's seal to this day.

And the U.S. Naval Observatory began providing a public time service in 1845.

Both of these public utilities were beneficial in and of themselves. But they were even more beneficial because their U.S. government provenance meant the provider was trustworthy, reliable, could be held accountable by the public, and services would be long-enduring.

Scrolling forward almost 200 years, the federal government followed the same process with GPS. It made GPS a PNT utility available to all, promised to broadcast high-quality signals in support of peaceful use and provide at least six years notice if it was to be discontinued (not near enough notice now, but it seemed sufficient back in the day).

To truly unlock the potential of unmanned systems, the U.S. must establish a resilient underlying PNT infrastructure.

The federal government has an enduring and important role providing PNT in support of national and economic security. At the same time, the feds can't do everything for everyone. So, when it comes to PNT for unmanned systems, where is the line between what the federal government ensures is available (either government owned or contracted and endorsed), and what commercial and private entities must provide?

The answer has huge implications for how unmanned systems are designed.

For example, if a platform can rely on a national resilient PNT backbone to navigate to within 5 meters of its destination, the number of additional on-board sensors and type of destination beacons may be very different than if it can arrive only within 500 or 1,000 meters.

The extent and nature of national PNT infrastructure will have a profound effect on how quickly the unmanned industry is able to implement and proliferate systems.

Signals from GPS and other GNSS can no longer be reliably received in many parts of the world. Noteworthy incidents within the U.S. have shown the nation is not immune to disruption and confirm statements by government officials that GPS alone is no longer enough.

While no federal leader or program has yet been identified, it seems the United States government must implement, or at least lead an effort to establish, a national resilient PNT architecture. Such an architecture must be able to act as a safety net in the event of a GPS disruption, and a backbone upon which owners and developers of PNT and unmanned systems can build and improve.

The exact performance requirements for a national resilient PNT architecture to support unmanned systems will most certainly be debated. Some overall characteristics seem clear, though, including:

Coverage: The ideal future of unmanned systems, especially in transportation, includes them being able to perform a range of routine to hazardous tasks almost anywhere.

For the United States, this includes vast stretches of desert, rugged and remote mountains, and offshore at least to the limits of the Exclusive Economic Zone (generally 200 nautical miles). The national PNT backbone should not require, for example, unmanned systems to have one set of navigation systems for the East Coast and another for the West.

Vulnerability and Failure Modes: Resilience and reliability is a system-of-systems effort. GPS will be the cornerstone of America's PNT architecture for decades to come. Navigation systems working with it to support unmanned systems must be as immune to the threats that endanger GPS signals as possible.

> **"Supporting the safety** and efficiency promises of unmanned systems may be the impetus for finally moving forward on a national resilient PNT architecture."

SWaP-C (Size, Weight, and Power–Cost): While important in every context, unmanned systems are especially sensitive to SWaP-C.

For these systems to proliferate and realize their full potential benefit to society, on-board PNT gear must be effective, but also small and lightweight. They must consume little power, and be as affordable as possible.

Although often constrained by the laws of physics, experience has shown technology SWaP-C can often be greatly reduced. For GPS, SWaP-C reduction from electronic racks on pallets to a microchip was driven by a combination of government-sponsored research and a virtuous cycle of system adoption, production at economic order quantities, and subsequent industry-led research.

Access: Ensuring signals could be accessed and used without cost by anyone with a view of the sky was critical to the adoption and success of GPS. This easy access greatly supported the virtuous cycle of adoption, use, research, improvement, greater use, reduction in SWaP-C, and increasing benefit to the nation. Unmanned systems should have access to non-GPS services from the national resilient PNT architecture that are as barrier-free as possible.

Broad Utility: Supporting the safety and efficiency promises of unmanned systems may be the impetus for finally moving forward on a national resilient PNT architecture.

It is in the interests of all, though, that architecture serve more than just unmanned systems, or even transportation. The technologies implemented should be as useful and accessible to a wide a range of applications as possible. Again, broad adoption and use will feed the virtuous cycle, and that benefits all.

Enduring Commitment: Few will be willing to commit to the trouble and expense of adopting services from a PNT architecture if the government only commits to the technologies for a short period of time.

Mariners rely on lighthouses because they are solid, dependable, and will be there for the foreseeable future. GPS users are confident it will be around for decades (even if they know about the provision for six years notice). Unmanned systems are unlikely to rely upon systems that won't be around for at least a few decades.

Looking Forward

At the moment, much of the focus around unmanned systems is how they can be instruments of war. It is a sad but recurrent theme in human history that armed conflict generates many technological advancements. Yet, the greatest long-term benefits from unmanned systems will most certainly be in their ability to automate hazardous and routine tasks and greatly increase productivity for civil society.

To realize those benefits, we must establish a resilient underlying PNT infrastructure, the lack of which is greatly constraining use of unmanned systems in the United States. This will first require creating much greater awareness of the need within both industry and government and then motivating all to take action. That is the only way to protect the nation and foster broad implementation of unmanned system for America's next phase of economic expansion. IG