BEYOND GPS: CHARTING AUSTRALIA'S PNT FUTURE IN AN UNCERTAIN WORLD

REVIEW OF INTERNATIONAL PNT POLICIES AND THEIR RELEVANCE TO AUSTRALIA

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FRONTIER SI

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FrontierSI respectfully acknowledges the Aboriginal and Torres Strait Islander people of Australia, first custodians of the lands, air and waters that sustain the places we live, work and play. These first peoples have had a vibrant, living culture that has remained in sustainable synergy with the natural environment for tens of thousands of years, and continues to do so.

We recognise that the lands of the Aboriginal and Torres Strait Islander people of Australia coexist with the Commonwealth of Australia.

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ACRONYMS

Acronym	Full form
ACSC	Australian Cyber Security Centre
AFRL	Air Force Research Laboratory (US)
AGO	Australian Geospatial-Intelligence Organisation
AIM	Assurance, Integrity, Monitoring
AMSA	Australian Maritime Safety Authority
APNT	Assured PNT
ASCA	Advanced Capabilities Strategic Accelerator (Australia)
ASECNA	Agency for Aerial Navigation Safety in Africa and Madagascar
AUKUS	Australia, the United Kingdom, and the United States
C3	Command Control and Communication
C-PNT	Complementary PNT
CACS	Canadian Active Control Station
CASA	Civil Aviation Safety Authority (Australia)
CGSIC	Civil GPS Service Interface Committee
CISA	Cybersecurity & Infrastructure Security Agency (US)
CISC	Cyber and Infrastructure Centre (Australia)
DG DEFIS	Directorate-General for Defence Industry and Space (EU)
DLORAN	Differential LORAN
DOD	Department of Defense (US)
DOT	Department of Transportation (US)
DARPA	Defense Advanced Research Projects Agency (US)
DHA	Department of Home Affairs (Australia)
DHS	Department of Homeland Security (US)
DME	Distance Measuring Equipment
DRDC	Defence Research and Development (Canada)
DSTG	Defence Science and Technology Group (Australia)
EC	European Commission
EEA	European Economic Area
EGEP	European GNSS Evolution Programme
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS
ELORAN	Enhanced LOng RAnge Navigation
ESA	European Space Agency
ESSP	European Satellite Services Provider
EUSPA	European Union Agency for the Space Programme
EW	Electronic Warfare
EWS	Emergency Warning Service
FAA	Federal Aviation Administration (US)
FGCB	Federal GNSS Coordination Board (Canada)
FCC	Federal Communications Commission (US)
GA	Geoscience Australia
GAO	Government Accountability Office (US)
GEODE	Galileo for EU Defence
GNSS	Global Navigational Satellite Systems
GPS	Global Positioning System
HAS	High Accuracy Service

Acronym	Full form
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
ILS	Instrument Landing System
IMO	International Maritime Organization
ISED	Innovation, Science and Economic Development (Canada)
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
JNWC	Joint Navigation Warfare Centre (US)
JPD	Joint PNT Directorate (Australia)
LEO	Low Earth Orbit
LORAN	LOng RAnge Navigation
MEO	Medium Earth Orbit
MIC	Ministry of Internal Affairs and Communications (Japan)
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
MOD	Ministry of Defence (UK)
MSAS	MTSAT Satellite-based Augmentation System (Japan)
NASA	National Aeronautics and Space Administration (US)
NAVISP	NAVigation Innovation and Support Program (EU)
NAVWAR	Navigation Warfare
NDB	Non-Directional Beacon
NICT	National Institute of Information and Communications Technology (Japan)
NIST	National Institute of Standards and Technology (US)
NMI	National Measurement Institute (Australia)
NPL	National Physical Laboratory (UK)
NRCAN	Natural Resources Canada
NSPS	National Space Policy Secretariat (Japan)
NTC	National Timing Centre (UK)
NTP	Network Time Protocol
NTS-3	Navigation Technology Satellite-3
OSNMA	Open Service Navigation Message Authentication
OSTP	Office of Science and Technology Policy (US)
PASR	Preparatory Action on Security Research (EU)
PNT	Positioning, Navigation and Timing
PRS	Public Regulated Service
PTA	Protect Toughen Augment
QZNMA	Quasi-Zenith Navigation Message Authentication
QZSS	Quasi-Zenith Satellite System
R-GPS	Resilient GPS
RAF	Royal Air Force (UK)
RIN	Royal Institute of Navigation (UK)
SBAS	Satellite Based Augmentation System
SOUTHPAN	Southern Positioning Augmentation Network
TACAN	Tactical Air Navigation System
UNOOSA	United Nations Office for Outer Space Affairs
USSF	US Space Force
VOR	VHF Omnidirectional Radio Range
WAAS	Wide Area Augmentation System

EXECUTIVE SUMMARY

Positioning, Navigation, and Timing (PNT) services are foundational to modern society, supporting critical functions across defence, emergency response, finance, transport, and energy systems.

Today, the dominant source of PNT services is Global Navigation Satellite Systems (GNSS), with many nations relying heavily on the US Global Positioning Service (GPS), including Australia. However, the threat landscape is evolving. As state and non-state actors develop means to deny, degrade, or manipulate access to space-based services, the resilience of PNT systems, and by extension, the security and stability of nations, is increasingly at risk.

This report reviews international approaches to PNT resilience across five key jurisdictions – the United Kingdom, United States, European Union, Canada, and Japan, with a lens on defence and national security dimensions, and their relevance to the Australian context.

Why Resilient PNT matters for Australia

Australia's primary reliance on GPS for its PNT services creates a strategic vulnerability, and leaves it exposed to almost single-point failure, with limited resilience in the face of emerging threats and global instability. As geostrategic competition intensifies and space becomes a contested domain, other nations are investing in alternative technologies and national strategies to mitigate GNSS reliance. In contrast, Australia lacks a cohesive national approach, a clear governance framework, and a dedicated risk oversight for PNT, despite Defence and industry recognising the criticality of the issue.

Without decisive government leadership to support resilient, sovereign, and multi-layered PNT capabilities, Australia risks cascading operational failures and functionality across both civilian infrastructure and military systems. Addressing this gap is essential in safeguarding national resilience.

Insights from international counterparts

United Kingdom

The UK has developed a cross-government National PNT Resilience Framework supported by a newly established National PNT Office. Its strategy focuses on building a system-of-systems architecture combining foreign-supplied GNSS, with terrestrial backups like eLORAN, sovereign timing centres, and next-generation technologies such as quantum. The UK Ministry of Defence is closely engaged in the National PNT Office, and either leads or co-leads initiatives specific to defence applications, ensuring alignment between national resilience objectives and military requirements. The UK demonstrates that national sovereignty in PNT can be achieved without owning a GNSS constellation, by asserting governance over outcomes.

United States

The US anchors its PNT strategy around GPS ownership and operational control, underpinned by joint civil-military governance model. Policy instruments such as Executive Order 13905 and Space Policy Directive-7 emphasise the protection and augmentation of PNT infrastructure, the need for complementary systems, and a robust approach to cyber and spectrum threats. The US also leads in fostering commercial innovation, with increasing exploration and testing of commercial and alternative capabilities. The National Executive Committee for Space-Based PNT, co-chaired by the US Department of Defense and Department of Transportation, oversees cross-government coordination. Within Defense, a tri-chaired PNT Oversight Council and the US Space Force manage military operations, including M-code capabilities.

European Union

The European Union is advancing a federated "system of PNT systems," leveraging the Galileo navigation satellite system and regional satellite-based augmentation system (EGNOS), alongside complementary technologies like fibre-optic timing, and future Low Earth Orbit platforms. Governance is distributed, but coordinated through the European Commission, the European Space Agency, and the EU Agency for the Space Programme. The EU model prioritises strategic autonomy through shared sovereignty and tightly regulated secure services, while promoting interoperability and civil-military alignment.

Canada

Canada offers a pragmatic model built around trusted partnerships, notably with the United States, and evidence-based assessments of PNT risk. While lacking sovereign GNSS assets, Canada is investing in alternative PNT research and fostering coordination through its interdepartmental PNT Board.

Japan

Japan's PNT governance is led at the executive level by the Cabinet Office, which oversees enabling functions of strategy, policy, research and development, and spectrum management, ensuring coordinated, whole-of-government oversight. Japan's Quasi-Zenith Satellite System (QZSS) demonstrates regional augmentation and GNSS complementarity. Designed to enhance GPS performance over Japan and neighbouring regions, QZSS integrates with other GNSS systems while offering unique timing and messaging capabilities, ensuring that both defence and civilian benefits are maximised. Japan positions PNT as critical infrastructure and incorporates space into its national security strategy, including civil-military integration for resilience.

A clear international consensus is emerging – resilient PNT requires a "system-of-systems" approach enabled by strong government leadership at the highest level. Nations are investing in a diverse mix of technologies, including satellite-based augmentation, terrestrial backup systems, quantum timing networks, and Low Earth Orbit PNT to create layered architectures that can withstand disruptions. Crucially, each country explored in this report demonstrates the importance of strong governance from the outset, with civil-military coordination and support for commercial innovation as key enablers of national PNT resilience.

Australia's national leadership in PNT resilience

While civil investment in Australia has focused on improving accuracy through GNSS augmentation services such as SouthPAN, these efforts do not address the core resilience challenge, namely the lack of redundant, alternative, or sovereign PNT systems that can maintain functionality at scale during disruption. On the defence side, reliance on delayed US GPS military code deployment, and a narrow focus on assured PNT for warfighting platforms, risks leaving support systems that depend on PNT, such as command and control, logistics, health networks, exposed.

Despite PNT underpinning a side array of national systems, Australia lacks:

- A national PNT policy, framework, or strategy;
- A dedicated governance structure for civilian or military PNT coordination or oversight of national PNT strategy;
- A clear lead entity responsible for coordinating risk identification and mitigation nationally;
- A consistent approach to user-level resilience and technology adoption.

To address this gap and in adapting international best practice to an Australian context, this paper recommends establishing a dedicated National PNT Office to lead cross-government strategy, coordination and PNT risk management. The office should be backed by enabling structures such as:

- A National PNT Coordination Council to advise and align on strategic priorities, share information, and coordinate efforts across diverse sectors, while supporting the whole-of-government PNT Working Group;
- A PNT accelerator to develop, test and scale domestic capabilities;
- A PNT assurance, integrity, and monitoring function to certify reliability and suitability across critical systems, for both defence and civil environments;
- A Defence PNT governance model to coordinate and manage classified, protected, and mission-critical applications.

Without a shift from fragmented, technology-centric efforts to a coordinated, outcome-driven approach focused on user resilience, Australia remains exposed to national security and economic risks. Reframing PNT as a national utility, essential to continuity, sovereignty and resilience, is needed to mobilise investment and coordinated action. A layered and user-focused strategy, enabled by good governance, can help Australia can enhance national security, protect critical infrastructure, and future-proof its PNT capabilities in an increasingly contested global environment.

1 INTRODUCTION

1.1 Background

In an increasingly contested and interconnected world, access to Positioning, Navigation, and Timing (PNT) services has emerged as a strategic imperative in many nations. PNT underpins not only civil infrastructure and economic productivity, but also the operational effectiveness, deterrence posture, and sovereignty of national defence forces. As actors develop means to deny, degrade, or manipulate access to space-based services, the resilience of PNT systems has become a critical concern globally.

For Australia, this challenge is compounded by its geographic scale, regional dependencies in the Indo-Pacific, and reliance on foreign-owned satellite systems, particularly the US-operated GPS. As a close defence and intelligence partner to the United States, and as a key actor in the Indo-Pacific, Australia must increasingly consider its PNT resilience through both a national and allied lens.

This paper contributes to the conversation by undertaking a targeted scan of international approaches to resilient PNT, with a particular focus on countries of strategic relevance to Australia: the United States (US), United Kingdom (UK), Canada, the European Union (EU), and Japan. Many of these nations have emerging or mature policies aimed at reducing reliance on single-source GNSS, diversifying PNT architectures, and in some cases, integrating civil and defence planning. It builds upon the earlier work of Critchley-Marrows and Verspieren that evaluated global navigation policies for a civil perspective [1]. It extends the focus to include defence and national security dimensions, with specific application to the Australian context.

This paper is developed by FrontierSI as part of broader effort to inform Australian Defence thinking on PNT resilience, including how civil infrastructure might be leveraged or coordinated to strengthen national security outcomes. It draws on both desktop research and engagement with international stakeholders who possess insight into governance models, national or regional policies, and civil-military coordination in their respective context.

1.2 Objectives

The objectives of the research are summarised below:

- To evaluate international PNT policies and initiatives that may hold relevance or adaptability for Australia;
- To explore how Australia's partners are responding to the increasing risks to PNT;
- To examine how nations approach PNT governance, technology diversification in PNT, and civil-military cooperation in growing PNT capability.

1.3 Approach

The approach taken to carry out the work is summarised below:

- Desktop review of official strategies, roadmaps, and programs related to resilient PNT;
- Semi-structured interviews with stakeholders in government, not-for-profit agencies, and/or defence institutions in selected countries;
- A comparative analysis of governance and policy settings, with a focus on Australia's current posture and options for action.

Each country chapter is structured to outline the national approach to PNT, including governance arrangements, technological diversity, perspectives on PNT sovereignty, civil-military coordination in infrastructure, and international collaboration for PNT resilience. These dimensions are then examined through an Australian lens, with commentary provided on Australia's specific challenges, and proposing an indicative governance structure to support a more coordinated dialogue.

As PNT increasingly underpins defence operations, economic and societal continuity, and national resilience, it is vital that Australia take stock of how other nations are adapting to emerging threats in this domain [2]. This paper provides an international comparative lens to inform Australia's next steps in securing and sustain access to trusted PNT both strategically, technically, and institutionally.

2 PNT IN A CHANGING WORLD

2.1 Growing dependence, growing risk

PNT services, currently delivered primarily through GNSS, are deeply embedded in civil infrastructure and military capability. Civilian sectors such as transportation, agriculture, telecommunications, energy, and finance rely on precise navigation and timing. In defence, PNT is essential for command and control, precision strikes, logistics, and force mobility.

However, reliance on GNSS comes with escalating vulnerability. GNSS signals are inherently weak and easily disrupted, whether by natural or physical hazards, unintentional interference, or deliberate interference through cyber or electronic warfare. Jamming and spoofing, combined with global advancements of counter-space capabilities, have significantly increased the risks to PNT, and hence, national resilience worldwide. Some nations, such as the UK and Japan, have developed national PNT strategies or initiatives, including investment in alternative PNT technologies, to mitigate reliance on single points of GNSS failure.

2.2 Geopolitical drivers and global strategic shifts

Globally, national defence and security postures are evolving in response to intensifying geostrategic competition. Australia's 2024 National Defence Strategy shifted the country from a defensive to deterrence posture, while formally elevating the space and cyber domains from supporting to operational domains alongside the land, maritime, and air services [3].

Australia has had a long-standing alliance with the US since the end of World War II. Through its membership in the Five Eyes, AUKUS and QUAD, Australia has greatly benefitted from US infrastructure, technology, and shared intelligence, including the GPS and its military channels. In early 2025, there has been a realignment of security postures in some countries, with geopolitics impacting the global status quo, introducing significant uncertainty into previously stable bilateral and multilateral relationships whilst also destabilising the global supply chain. Australia's reliance on the US as a strategic partner, especially in the Indo-Pacific region, reinforces the need for greater resilience and proactive management in critical domains, including PNT.

GNSS constellations, including GPS, are space-based assets, and recent shifts in policy language reflect the evolution of how global powers frame the strategic importance of the space domain. In April 2025, the US Space Force (USSF) Doctrine Document formally designated space as a "warfighting domain" [4], directly influencing how space-based capabilities are protected and employed. In contrast, Australia still officially refers to space as an "operational domain" [5], though the persistent framing of space as "contested" in national narratives (including civilian) similarly positions it within an offensive context [6]. Regardless of terminology, PNT is a cross-domain capability that underpins Australian Defence operations in the land, air, maritime, space and cyber domains. Australia's primary reliance on the US-operated GPS introduces significant vulnerability, exposing our access to space-based PNT services as not only a crippling dependency, but one increasingly recognised as a target and tool of competition and conflict.

2.3 Sovereign PNT

The ability to provide assured, uninterrupted PNT services is increasingly viewed as a core element of national sovereignty. PNT underpins critical infrastructure, economic activity, and military capability. If a nation cannot guarantee continued access to these services, especially in a time of conflict, it risks losing strategic autonomy in both civilian and defence contexts.

Some nations have pursued the path of owning a space-based constellation for both geopolitical and economic reasons. The European Union's Galileo program was developed with dual goals – reducing dependency on US systems and stimulating growth in Europe's space economy. China's BeiDou system was similarly motivated by broader space ambitions and independence from GPS.

However, full space-based capability is not the only path to sovereignty. Most countries can achieve a sovereign PNT posture without owning a satellite constellation. Robust, resilient terrestrial systems, such as fibre-distributed timing, eLORAN and quantum-enhanced navigation among others, can provide national coverage and operational independence. These systems offer sovereign control while still benefiting from the strengths of space-based services, supporting a balanced and layered PNT architecture that reflects national priorities and risk tolerance.

2.4 Resilient PNT

In the context of this paper "resilient PNT" terminology refers to policies, strategies, and initiatives, which serve to broadly encompass the concepts of assured PNT, augmented PNT, alternative PNT, backup PNT, and complementary PNT, as used by various countries. Here, the definition of resilient PNT follows that articulated in Critchley-Marrows and Verspieren [1], being the following:

> *The ability of the PNT service to recover and/or continue operation, with some acceptable degradation to satisfy critical needs, in the face of adversity.*

Resilient PNT underpins defence counter-PNT operations, where "resilient PNT" is foundational and defensive, whereas "counter-PNT" is active and offensive. Note that this paper does not include discussions about counter-PNT strategies specifically, such as for operations aimed at degrading adversarial access to PNT. Nevertheless, it is acknowledged there are blurred boundaries between resilience and counteraction, particularly in the context of navigation warfare (NAVWAR), Electronic Warfare (EW), and cyber warfare.

The next chapter provides the various country summaries and their approaches to resilient PNT.

3 INTERNATIONAL PNT POLICIES: NATIONAL APPROACHES

This chapter provides an overview of national approaches to PNT, including policies or strategies for the United Kingdom, United States, European Union, Canada, and Japan, with a lens on defence and national security. For each country, the approaches to PNT sovereignty, technological diversity, civil-military coordination for infrastructure, and international collaboration are explored.

3.1 United Kingdom

UK is pioneering a system-of-systems approach, where PNT is not treated as a singular capability, but as a layered infrastructure spanning space-based signals, terrestrial systems, and trusted timing sources. The UK has developed an effective cross-government national PNT framework that emphasises coordination, risk awareness, and shared responsibility across the defence and civilian sectors.

3.1.1 UK approach to PNT

The UK illustrates the strategic risks associated with reliance on foreign GNSS, making it vulnerable to geopolitical shifts. Prior to "Brexit", the UK was part of the European Union with full member access to the Galileo program, including benefits of its encrypted services. Following its withdrawal from the EU, the UK retains access to the publicly available components of Galileo, but no longer benefits from the Public Regulated Service (PRS) that is critical for national security and defence [7]. Neither does the UK inform or contribute to areas of its development that might best serve the national interest. Like other Five Eyes nations, the UK is primarily reliant on GPS, and utilises the other GNSS systems only when high-accuracy services are of interest.

3.1.1.1 A coordinated national PNT resilience framework

The UK maintains a National Risk Register for contingency planning and the loss of PNT has been included explicitly as a standalone risk for the first time since the 2023 edition. This has highlighted a shared national understanding of the importance of PNT for a diverse range of essential functions across an increasingly interconnected society [8]-[9].

The UK has taken a whole-of-government approach to PNT through its cross-government National PNT Resilience Framework [10]. The 10-point framework outlines key actions and responsibilities, and covers both civil and defence domains [11].

While the National PNT Resilience Framework was only announced in 2023, and the establishment of a dedicated PNT Office in 2024, there have been ongoing attempts to formalise national coordination for over two decades. From a policy perspective, the Royal Institute of Navigation (RIN) has played a significant role in advocating for PNT awareness, with recent initiatives including:

- Leading the UK PNT Advisory Group that brings together the UK PNT ecosystem to share knowledge, develop positions and key issues, and provide expert-led advice, such as through its 2023 White Paper Recommendations to Promote Adoption of Resilient PNT in the UK [12];
- Development of the Resilient PNT Resources Portal, which provides guidance and best practice on resilient PNT for critical infrastructure [13];
- Collaborating with the UK National Preparedness Commission to report on *Preparing for a Loss of Position and Timing* that helped frame the National PNT Resilience Framework [14];
- Contributing to the Ops Group GPS Spoofing Final Group Report on the impact of GPS Spoofing on the aviation industry and flight safety [15]. Noted support from the UK Ministry of Defence (MOD) and UK Royal Air Force (RAF) on this work highlighted the criticality of the issues of GPS spoofing, not just to aviation as a civilian critical infrastructure sector, but also to defence air as a warfighting domain.

3.1.2 Governance

Housed within the departmental structure of the Department of Science, Innovation and Technology, the National PNT Office is not a regulatory body, but works across government to deliver the Framework, which sets out the current and future focus for UK government PNT policy [16]. The focus areas include:

- National PNT Office;
- PNT Crisis Plan;
- National Timing Centre (NTC);
- MOD time;
- eLORAN ;
- Next Generation PNT;
- PNT Growth Policy;
- PNT Skills;
- UK Satellite Based Augmentation System (SBAS);
- Infrastructure Resilience.

Whilst the Framework represents a collection of valuable initiatives, it does not constitute a coherent, strategy-led approach. It blends capability programmes with planning and workforce development, but lacks an overarching strategy that clearly prioritises objectives or links them to national outcomes. Moreover, the National PNT Office is structured for coordination rather than operational delivery, limiting its ability to drive implementation at scale.

The National PNT Office leads the coordination of the components of the Framework, though some of these components have designated operational (and hence governance) leads from other government agencies (refer to Figure 1).

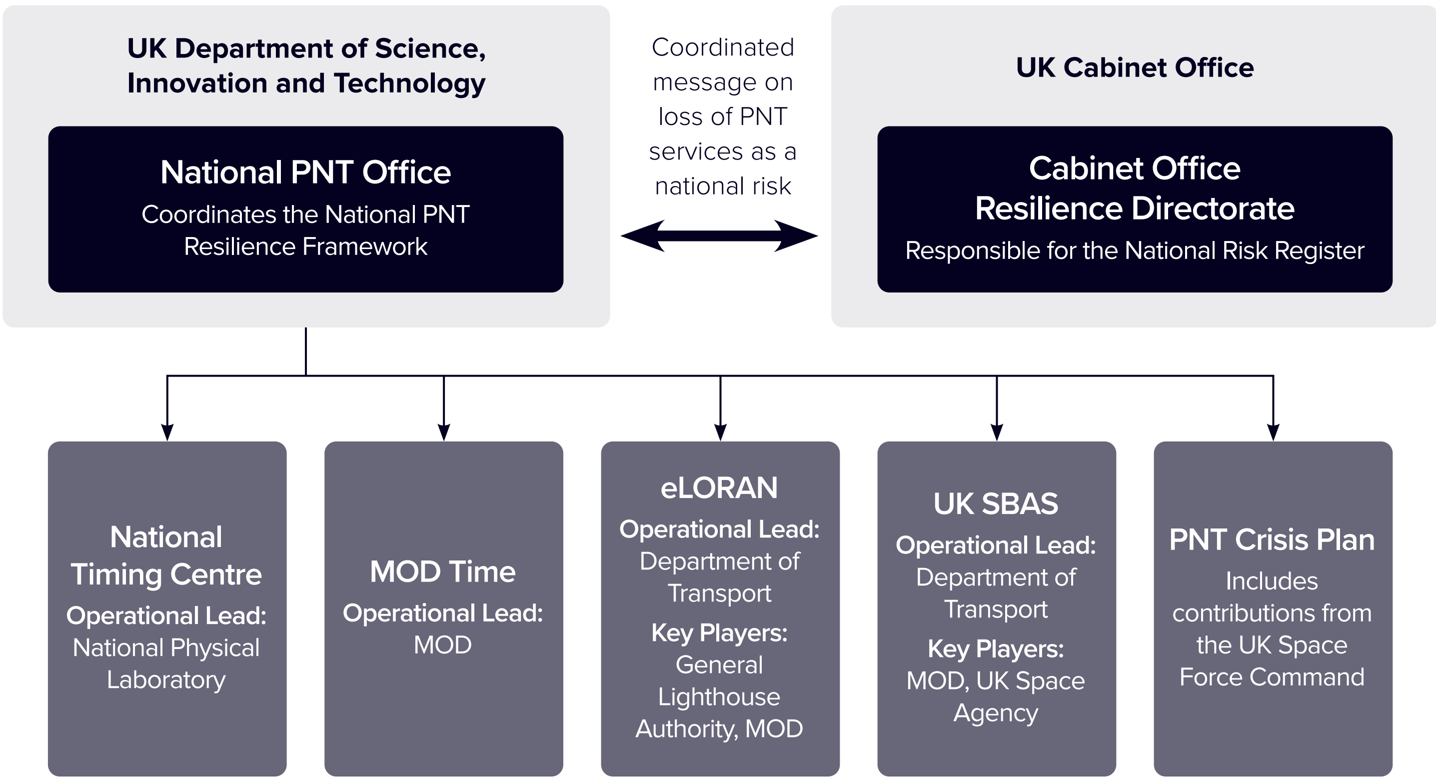

Figure 1. UK PNT governance structure.

The focus areas are intended to be integrated with the UK's use of foreign-owned GNSS to form an assured capability framework, enabling trusted PNT from reliable sources, including close allies. There is expressed interest among the UK PNT community to investigate possible options for a UK sovereign regional satellite system, as well as the exploration of Quantum PNT capabilities. Whilst there are no formal government programmes specifically announcing the development of sovereign satellite navigation capabilities, Innovate UK has invested in a number of Quantum PNT projects, supporting technologies such as quantum-enhanced sensors and inertial navigation systems [17]. These investments highlight emerging interest in GNSS-independent solutions, although a coordinated, whole-of-government approach is not yet evident. These have been implied in what is possible within the scope of the National PNT Resilience Framework. However, at the time of the research for this report, there are no official programs or announcement of formal government investments announced in the UK.

3.1.3 Technological diversity

As discussed in the previous section, the United Kingdom is pursuing a system-of-systems approach to PNT, with technological diversity emerging as a cornerstone of its national resilience strategy. The aforementioned Framework for PNT Resilience and Innovation integrates multiple technologies across space, terrestrial, and timing domains, and is planned to be carried out over two distinct phases, which are referred to as "epochs".

Epoch 1 will utilise current and proposed as well as partially funded capabilities over the next few years. Epoch 2 will follow on and build on Epoch 1 to build diversified nation-wide terrestrial-based timing infrastructure based on the network of atomic clocks distributed around the country under the NTC programme [18] as well as the nationwide eLORAN network [19]. While the UK government will invest significantly in Epoch 1, the nature of several Epoch 2 capabilities may lend themselves more to private or industry-led development, such as quantum navigation, 5G, and LEO PNT services [20].

Whilst industry partnerships have many advantages, they also carry an inherent risk of financial instability or business failure, which must be factored into national planning. While this has not happened explicitly for PNT, one relevant example cited was the UK government's intervention to rescue OneWeb satellite communications infrastructure, highlighting the strategic vulnerability of relying solely on the private sector for critical infrastructure.

It is also important to acknowledge that the historic dominance of free-to-air, government-operated services, such as GPS, has inadvertently stifled innovation in non-GNSS alternatives. The availability of highly reliable satellite PNT at no direct cost to user has reduced the commercial incentive to develop and invest in complementary or alternative systems. This has been recognised by the United States government itself, which is now re-evaluating the long-term impacts of the "free-to-access" model and its implications for national resilience and industrial competitiveness [21]. Similar considerations may need to inform the UK's approach to future PNT investment and innovation policy.

eLORAN has been identified as a critical terrestrial technology for backup PNT, particularly in maritime and coastal regions where GNSS interference is most prevalent. A modernised version of the legacy LORAN-C system, eLORAN transmits low-frequency radio signals from terrestrial towers to provide timing and positioning information independent of satellites. The UK is developing a sovereign, deployable eLORAN capability to provide a geographically robust fallback system.

In the timing domain, the NPL and the NTC are central to efforts to ensure resilient time dissemination. The NTC programme supports both civilian and military users, providing accurate and secure time via fibre-based networks and holdover atomic clocks.

Emerging technologies also form part of the UK's future PNT posture. Government and industry are jointly exploring Alternative PNT (APNT) technologies such as quantum PNT, inertial systems, 5G positioning, and LEO PNT constellations, recognising that these hold promise for GNSS-independent navigation in contested or denied environments. These technologies are expected to play a greater role in the next generation of PNT services, particularly in urban or underground settings where satellite signals are degraded or unavailable.

The UK's approach to technological diversity is not only about redundancy, but about creating a resilient, layered, and interoperable PNT ecosystem. By integrating space-based systems with terrestrial signals, fibre timing networks, and next-generation technologies, the UK aims to ensure PNT services remain available, accurate, and secure even under adverse conditions.

3.1.4 UK perspectives on sovereignty

The United Kingdom adopts a nuanced and layered interpretation of PNT sovereignty, one that moves beyond traditional notions of infrastructure ownership to focus instead on assured service delivery, operational autonomy, and strategic resilience. Through whole-of-government endorsement and coordination, the UK has signalled that achieving sovereign PNT capabilities does not necessitate building or owning a national GNSS constellation. Instead, sovereignty is pursued through a hybrid framework that integrates trusted foreign GNSS services with nationally governed terrestrial systems, sovereign timing infrastructure, and data fusion capabilities.

At the heart of this approach is the recognition that sovereign control over outcomes is more important than full ownership of upstream assets. This specifically incudes the ability to ensure availability, integrity, and continuity of PNT services for critical infrastructure. This is especially relevant in an era of increased global interdependence, where multi-GNSS receivers are the norm and resilience stems from diversity and redundancy, not singular dependence. The caveat is that there needs to be assuredness and trust in each system component. Without confidence in their performance, even technically diverse architectures may fall short of delivering truly resilient national capability.

The UK's National PNT Resilience Framework articulates this vision clearly. Sovereignty is exercised through initiatives such as the development of a national eLORAN capability for terrestrial fallback, the establishment of the NTC to provide holdover and traceable time independent of GNSS, and exploration of emerging technologies like quantum PNT and LEO-based navigation services. These measures provide the UK with a sovereign layer of assurance, allowing it to detect disruptions, switch to alternative sources, and continue delivering trusted PNT services under stress or attack.

Furthermore, by investing in sovereign capabilities for data fusion and situational awareness, the UK ensures that it retains control over how PNT data is interpreted, validated, and used across sectors. This is particularly critical for defence, transportation, telecommunications, and energy networks, where real-time positioning and timing data must be resilient to threats like spoofing and jamming.

The UK's approach also acknowledges the risks of over-reliance on commercial and foreign entities for critical services. While GPS remains essential building blocks of the UK's PNT architecture, the lack of guaranteed access to Galileo's Public Regulated Service (PRS) post-Brexit highlighted the geopolitical vulnerability of not maintaining sovereign fallback capabilities. As such, UK policy now favours a sovereign-by-design model, where domestic control, trusted partnerships, and layered technologies are combined to preserve national freedom of action.

The UK defines PNT sovereignty not by the origin of satellite signals alone, but by its ability to ensure continuous, secure, and trustworthy PNT services delivered under national authority, aligned with strategic interests, and resilient to global uncertainties. This framing allows the UK to chart a middle path – sovereign in outcome, collaborative in architecture.

3.1.5 UK civil-military strategic coordination in PNT infrastructure

The UK NTC, a long-term, national asset to support timing resilience across sectors, is a key example of shared and separate components serving civil and defence needs. The UK MOD has clear involvement in leading military-specific elements within the UK National PNT Resilience Framework, such as:

- Development of "MOD Time" supported by timing provided by the NTC. In the event of loss of timing to the national PNT system-of-systems, as delivered by the UK NPL to the NTC, the MOD also acts as a Contributor as 'System of Last Resort';
- Development of a deployable terrestrial and sovereign eLORAN network to provide backup positioning, navigation and timing [22]-[23];
- Representation in the National PNT Office, as PNT increasingly rises as a space-based priority for the MOD;
- Within the PNT Crisis Plan, the UK Space Operations Command monitors GNSS interference that would affect UK PNT services, and alerts the broader MOD and international partners to threats [24]. This PNT situational awareness role would cover both multi-GNSS and eLORAN monitoring systems across the UK;
- Multi-GNSS and eLORAN receiver development to ensure technology adoption by users.

While some PNT infrastructure is dual-use, the UK defence sector retains separate, application-specific technologies tailored for military operations. There is however a broader trend towards increasing overlap in areas like timing and resilient receiver development.

Receiver technology is being increasingly designed to serve both civilian and defence users. Next-generation receivers such as EnSilica [25] and Qinetiq Q40 [26] are being equipped with enhanced anti-jamming and anti-spoofing capabilities. Aside from conventional GNSS, these receivers are also being designed for future signals from emerging LEO PNT constellations.

It should be noted that while the end goal is a PNT system of systems, at this stage the various developments are building various capability layers, each addressing different threats, environments, and operational needs, rather than a fully integrated solution.

3.1.6 International collaboration for PNT resilience

Dependence on GPS primarily means that international collaboration is essential to improving the resilience of PNT infrastructure in the UK. A key consideration is the deliberate choice of allied nations, preferably those with shared values and strategic alignment, to ensure mutual technical and security benefits. Some examples include:

- The 10-point framework was developed with significant engagement with European allies, the Five Eyes nations, academia, industry, and ESA's Navigation Innovation and Support Program (NAVISP) [27];
- There are collaboration opportunities for the UK SBAS component of the Resilient PNT Framework with Australia, leveraging Australia's expertise and experience on delivering the SouthPAN SBAS [20].

Pooling resources is particularly beneficial in areas such as hardware development, where global supply chain constraints remain a significant obstacle. In a comprehensive review of the holdover atomic clock landscape [28], the NPL identified limited domestic industrial capacity to produce high-stability atomic clocks at scale, an issue further exacerbated by a global shortage of key components, such as oscillators, which are often required even for imported devices. Collaborative investment could help close such gaps while distributing the associated costs and effort.

The UK National PNT Office pointed to the need for shared situational awareness, understanding what other countries are developing and planning in PNT technology, and the potential for coordinated initiatives. For instance, in addition to space-based time transfer methods (via GNSS), the UK is investing significantly in terrestrial (fibre-based) time transfer as a resilient backup timing source. This approach is now being considered by other countries, including initiatives to link up European national time laboratories to disseminate time over resilient ground-based networks [29].

These efforts demonstrate that meaningful, security-conscious collaboration is already happening and could be expanded through structured partnerships and shared technical roadmaps.

3.1.7 UK Summary

The UK has developed a cross-government National PNT Resilience Framework supported by a newly established National PNT Office. Its strategy focuses on building a system-of-systems architecture combining foreign-supplied GNSS, with terrestrial backups like eLORAN, sovereign timing centres, and next-generation technologies such as quantum. The UK Ministry of Defence is closely engaged in the National PNT Office, and either leads or co-leads initiatives specific to defence applications, ensuring alignment between national resilience objectives and military requirements. The UK demonstrates that national sovereignty in PNT can be achieved without owning a GNSS constellation, by asserting governance over outcomes.

3.2 United States

The US outlook on PNT resilience is one of ownership and operational control of PNT assets, multi-agency government coordination, and policy leadership. Space-based PNT assets include GPS, and the US SBAS, which is known as the Wide Area Augmentation System (WAAS). Policies related explicitly to PNT, such as Executive Order 13905 and Space Policy Directive-7, focus on requirements, cross-sectoral planning for critical infrastructure, and directives for investment into diverse PNT sources. Stakeholders in the US consistently advise on prioritising: i) enhancing user resilience; ii) enabling a pathway for commercial delivery of capabilities; and iii) elevating PNT as a national priority that bridges civil and defence domains.

3.2.1 US approach to PNT

3.2.1.1 PNT Policy

Table 1 below briefly describes the key national policy documents governing PNT resilience. Together these policies outline a broad whole-of-government approach to ensuring resilient, secure, and modernised PNT capabilities across both civilian and defence domains.

US PNT-Relevant Policies	
2020 Executive Order 13905	EO-13905 focuses on safeguarding critical infrastructure from disruptions to PNT services. It tasks federal agencies with developing PNT risk profiles, vulnerability assessments, and securing access to GNSS-independent timing sources. It also instructs procurement officers to include PNT resilience requirements in federal contracts and assigns a lead to develop alternative and complementary PNT solutions. This policy allows the US to manage PNT as a foundational infrastructure asset, not just a technical system [30].
2020 National Space Policy	The National Space Policy outlines strategic directives concerning GPS, such as to maintain and modernise GPS to ensure uninterrupted, free global access for peaceful uses. The policy promotes international cooperation for interoperability, while encouraging the adoption of complementary and resilient PNT capabilities [31].
2020 Space Policy Directive-5	Space Policy Directive-5: Cybersecurity Principles for Space Systems establishes cybersecurity principles for the protection of space systems, including those that provide PNT functions, from malicious activities such as jamming and spoofing [32].
2020 C3 Modernization Strategy	The C3 Modernization Strategy outlines the DOD's approach to modernising Command, Control, and Communications capabilities to enable joint all-domain operations. It recognises resilient and assured PNT as a foundational enabler of C3, and calls for the integration of alternative PNT technologies to ensure operational effectiveness in degraded or denied environments [33].
Directive-7	Space Policy Directive-7: US Space-Based Positioning, Navigation and Timing Policy establishes implementation actions and guidance for US space-based PNT. It reaffirms the US commitment to providing open and free GPS services globally, while encouraging system modernisation, international collaboration, and spectrum protection. The policy also calls to "Invest in domestic capabilities and support international activities to detect, mitigate, and increase resilience to harmful disruption or manipulation of GPS, and identify and implement, as appropriate, alternative sources of PNT for critical infrastructure, key resources, and mission-essential functions" [34].
2023 DOD Directive 4650.05	Directive 4650.05 Positioning, Navigation and Timing assigns responsibilities for the DOD's PNT enterprise to ensure protection of PNT services for US and allied forces, while preventing adversarial use in areas of military operations [35].

Table 1. US national PNT policy documents.

Additionally, several departments have developed nationally-endorsed frameworks for PNT risk management, such as:

- The Cybersecurity & Infrastructure Security Agency's (CISA) Resilient PNT Conformance Framework that provides guidance for defining expected behaviours in resilient PNT equipment [36];
- The National Institute of Standards and Technology (NIST) NIST IR 8232 Foundational PNT Profile, that offers a PNT Profile based on the NIST Cybersecurity Framework for organisations to manage PNT risks as part of a risk management program [37].

The modernisation of the GPS was officially authorised by congress in 2000, which included new ground stations and satellites, alongside additional signals for both defence and civilian users. The Military(M)-code signal was introduced on each band as a new version of the traditional P(Y)-code. Alongside original encryption, it permits for signals to calculate a position and time independently to the civilian signal, improving system resilience. Spot beams are also included on each antenna, so receivers falling directly below the satellite may receive a higher power signal.

However, PNT policy is established in line with the United States Code, which is a compilation of statutes, organised into various titles. The foundational title is Title 10, summarised as:

'Title 10 of the U.S. Code, Section 2281, assigns the Secretary of Defense statutory authority to sustain and operate GPS for military and civil purposes. The statute directs the Secretary of Defense to provide civil GPS service on a continuous, worldwide basis, free of direct user fees. It directs the Secretary of Defense to coordinate with the Secretary of Transportation on GPS requirements and GPS augmentation systems, and to coordinate with the Secretary of Commerce and others to facilitate civil and commercial GPS uses. The statute directs the Secretary of Defense to develop measures for preventing hostile use of GPS in a particular area without hindering peaceful civil use of the system elsewhere. It requires the Federal Radionavigation Plan to be published every two years. Title 10 of the U.S. Code, Section 2279b, establishes the Council on Oversight of the Department of Defense Positioning, Navigation, and Timing Enterprise. The Council is responsible for oversight of the DOD PNT enterprise, including PNT services provided to civil, commercial, scientific, and international users. 10 U.S.C. § 2279b was created by Section 1603 of the National Defense Authorization Act for Fiscal Year 2016'. [38]

3.2.2 Governance

GPS infrastructure in the US cuts across both civilian and defence domains. At the federal level, PNT is governed by the National Executive for Space-Based PNT (refer to Figure 2). This National Executive is co-chaired by the Deputy Secretary of Defense and the Deputy Secretary of Transportation, symbolising the joint civil-military responsibility. It forms the nexus between the White House (which passes down Executive Orders), a NASA-sponsored Advisory Board, and the National Coordination Office hosted by the Department of Commerce.

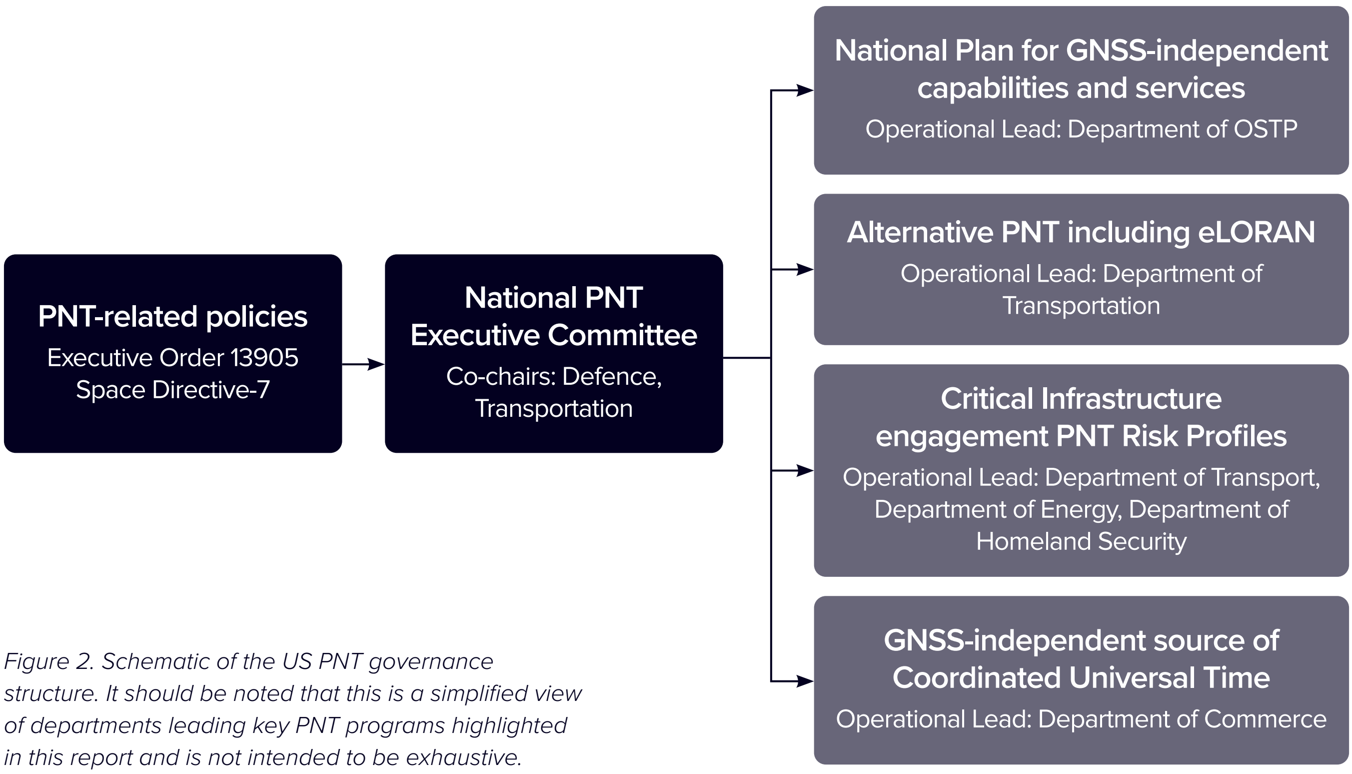

Figure 2. Schematic of the US PNT governance structure. It should be noted that this is a simplified view of departments leading key PNT programs highlighted in this report and is not intended to be exhaustive.

The US Department of Defense (DOD) maintains its own robust structures for PNT, including a tri-chaired enterprise-level PNT Oversight Council, as established under DOD Directorate 4650.05. However, because of statutory constraints, civilian oversight of GPS falls under the Department of Transportation (DOT) [39].

DOD Directive designates the DOD Chief Information Officer as the Principal Staff Assistant for PNT policy and coordination, and established the PNT Oversight Council. From the perspective of operations, GPS is under the jurisdiction of the USSF, where since 15 October 2024, it is under the responsibility of Mission Delta 31.

With regard to coordination of the M-code, the following responsibilities are established:

- Space Force – develops, acquires, and operates M-code capable GPS satellites;
- Space Command – operational use and integration into joint warfighting;
- Joint Navigational Warfare Centre (JNWC) – NAVWAR testing, M-code validation, and threat response support;
- DOD Chief Information Officer Policy, guidance, and integration in relation to M-code into platforms, such as via the C3 Modernization Strategy [33].

Despite these structures, the President's PNT Advisory Board, which is an independent advisory body established to guide national PNT strategy and policy, and Congress' Government Accountability Office (GAO) have respectively criticised national and DOD governance as unfocused and ineffective. The advisory board identified this as the single greatest obstacle to improving national PNT resilience [40].

3.2.3 Technological diversity

The United States recognises that while GPS remains foundational to its PNT capabilities, increasing dependence across critical infrastructure, defence, and commercial domains necessitates a broader, more diverse technology base. To this end, the US seems to be pursuing a multi-pronged approach framed under the national Protect, Toughen, and Augment (PTA) strategy. Each strand of this framework supports the broader aim of PNT resilience in the face of natural threats, signal interference, spoofing, and geopolitical disruption [41].

While EO 13905 calls for the establishment of diverse PNT sources as backups to GPS, most other US national policies and the broader governance structure for PNT remain heavily focused on space-based PNT. As such, no proactive steps towards resilience have been taken other than the publication of strategies and executive orders. According to the PNT Advisory Board, governance issues seem to be hindering government leadership and action [40].

3.2.3.1 GPS and WAAS

GPS is the backbone of the US PNT architecture. Modernisation efforts have introduced new civil and military signals (such as L5 and M-code), stronger signal power, anti-jam spot beams, and more accurate clocks onboard satellites. These improvements contribute to increased system robustness, particularly for authorised users and safety-critical applications.

To enhance precision and integrity regionally, the WAAS provides a satellite-based augmentation service across North America. Operated by the FAA, WAAS is crucial for aviation, enabling precision approaches under instrument flight rules, and supports a range of civil uses including agriculture and maritime navigation.

Despite these strengths, the US government acknowledges that GPS alone is not sufficient to meet modern resilience requirements. Civil GPS receivers were historically developed under the assumption of a clean spectrum and benign operating environment – an assumption that no longer holds.

3.2.3.2 R-GPS and LEO PNT

To strengthen the resilience of its space-based positioning capabilities, the United States Space Force is advancing a strategy known as Resilient GPS (R-GPS). This initiative involves the development of new, space-based assets that augment the legacy GPS constellation by enhancing its robustness in contested or degraded environments.

Unlike previous approaches that focused primarily on receiver-side hardening, the current emphasis is on deploying supplementary PNT satellites in MEO that operate in coordination with GPS. These satellites are designed to deliver interoperable or complementary PNT signals, enabling continued service even if parts of the core GPS constellation are denied, degraded, or disrupted.

In 2023, the DOD selected four US companies to develop small, resilient PNT satellites for deployment in MEO. The goal of this program is to rapidly deploy alternative sources of secure and precise positioning, navigation, and timing that can support military operations and critical national infrastructure [42]. These satellites are envisioned to:

- Operate independently or in synchronisation with GPS;
- Provide redundancy through diverse waveforms, frequencies, or orbital characteristics;
- Be deployed more quickly and flexibly than traditional GPS satellites.

This MEO-based augmentation forms a key element of the PTA framework. R-GPS provides the DOD and allied users with a layered architecture where GPS remains the primary system, but is now supported by a supplementary constellation tailored for operational continuity under threat.

In parallel, the US is also exploring complementary architectures in LEO through commercially-led initiatives. LEO PNT is emerging as a promising complementary system to GPS. LEO satellites offer faster signal dynamics, higher signal strength at the receiver, and coverage in environments where GNSS signals struggle, such as dense urban canyons. A number of private-sector companies are currently developing LEO-based PNT constellations [43].

While these systems are still in various stages of deployment, they represent a shift toward public–private partnerships to deliver next-generation navigation services. US government agencies such as DARPA, NASA, and the USSF are monitoring these developments and exploring their integration into national resilience frameworks.

Together, R-GPS and LEO PNT efforts reflect a broader shift toward diversified, multi-orbit PNT resilience.

3.2.3.3 NTS-3 and Experimental PNT Platforms

The Navigation Technology Satellite-3 (NTS-3) represents a key component of the United States' approach to experimenting with advanced technologies for resilient space-based PNT. Developed under the direction of the Air Force Research Laboratory (AFRL), NTS-3 is an experimental testbed satellite designed to demonstrate new capabilities in navigation signal flexibility, antenna beam steering, signal authentication, and autonomous onboard PNT operations. Apart from the satellite platform NTS-3 will also test ground-based command and control system and agile software-defined user receivers [44].

3.2.3.4 C-PNT Technologies

Resilient PNT can include other systems such as terrestrial radio signals and fibre-based timing networks. EO 13905 does acknowledge this need and has directed:

- Department of Commerce, Homeland Security (DHS), and Department of Transportation with identifying and testing alternative PNT services;
- DHS Cybersecurity and Infrastructure Security Agency (CISA) to assess PNT vulnerabilities across critical infrastructure sectors;
- The DOD for securing military PNT needs (i.e., NAVWAR).

While EO 13905 includes eLORAN as a potential backup capability, the US no longer supports the legacy LORAN system. Despite repeated recommendations from the US PNT community to develop an eLORAN as a terrestrial complement to GPS, there have been no recent efforts to preserve or modernise the former LORAN infrastructure. In fact, many of the former LORAN transmission sites are slated for demolition [45].

Although EO 13905 names the Office of Science and Technology Policy (OSTP) as the coordinator for R&D on alternative or complementary PNT, it is the DOT, through its Volpe Centre, that has become the operational lead for exploring and comprehensive testing of alternative PNT systems [46], as well as delivery of a Complementary PNT Action Plan [47]. More recently, the Federal Communications Commission (FCC) has issued a draft Notice of Inquiry to seek input on the development of alternative PNT technologies to complement GPS, including space-based augmentation, terrestrial networks, and secure user equipment [48].

3.2.4 US perspectives on sovereignty

While "sovereignty" is not directly mentioned, Space Policy Directive-5 states that: *"… the United States considers unfettered freedom to operate in space vital to advancing the security, economic prosperity, and scientific knowledge of the Nation…Therefore it is essential to protect space systems from cyber incidents in order to prevent disruptions to their ability to provide reliable and efficient contributions to the operations of the Nation's critical infrastructure"* [32]. Implicit in this policy is the need for sovereign ownership and control of space-based PNT for defence and critical infrastructure resilience.

While GPS is provided as a global public good and is free to use for peaceful purposes, it remains a strategic asset. The US government thus retains the authority to degrade or deny access to GPS, as per SPD-7: *"…to deny hostile use of United States Government space-based PNT services, without unduly disrupting civil and commercial access to civil PNT services outside an area of military or homeland security operations"* [50].

Although no public instances of GPS denial by the US Government have been recorded, they have shown a willingness to use access to strategic commercial space assets as geopolitical leverage. For example, China cited the "Unforgettable Humiliation" during a 1996 standoff with Taiwan [50], while India described a sense of betrayal during the 1999 Kargil conflict with Pakistan [51] – both cases involving the denial of GPS access at critical moments.

These instances have led China to BeiDou, and India to NAVIC to ensure they have sovereign space PNT capabilities. In another example, access to the Starlink communications system has reportedly been used as a bargaining tool in the context of international negotiations and conflict zones [52], highlighting how space-based infrastructure can be employed to support broader national objectives.

3.2.5 US civil-military coordination in PNT infrastructure

The original motivation for developing a GPS in the USA was from a military standpoint, even though potential civilian benefits were perceived and understood. This created a separation in requirements development, where it was not until 2023 a Memorandum of Agreement was signed between the Department of Defense and the Department of Transportation, establishing Civil Use cooperation for the Use of GPS, with assigned responsibilities between each entity [50].

Culturally and politically, the US has long maintained strict institutional boundaries between civil and military spheres, especially when it comes to infrastructure and data governance. This separation, while rooted in democratic values, can hinder the development of a cohesive national strategy. In contrast, more authoritarian countries have no such divide and are able to align defence and civilian capabilities under a unified system more easily.

At the strategic level, economic prosperity is increasingly recognised as an integral component of national power. Civilian systems such as finance, logistics and telecommunications are all critically reliant on PNT, just as defence systems are. In reality, the benefits of PNT do not fall neatly along sectoral lines. When discussions are separated by agency or domain, the broader picture of national resilience and capability can be lost. A more integrated approach is needed – one that acknowledges the indivisibility of PNT infrastructure and fosters collaboration across all sectors of national interest.

3.2.6 International collaboration for PNT resilience

SPD-7 directs the US to: *"Engage with international GNSS providers to ensure compatibility, encourage interoperability with likeminded nations, promote transparency in civil service provision, and enable market access to United States industry"* [34].

The US promotes international collaboration and engagement through formal multilateral forums, bilateral partnerships, and ongoing outreach to the global civil PNT community. One of the mechanisms for international cooperation is the International Committee on GNSS (ICG) [53], a United Nations forum that facilitates coordination among GNSS provider and user states. The US State Department provides financial support to the ICG, while the United Nations Office for Outer Space Affairs (UNOOSA) serves as its secretariat. Through the ICG, the US contributes to discussions on spectrum protection, signal interoperability, and use of complementary systems in support of resilient PNT globally.

The US also hosts the Civil GPS Service Interface Committee (CGSIC) annual meetings and conferences [54]. Administered by the US Coast Guard and DOT, the CGSIC forms a forum for civilian GPS users to provide updates on GPS modernisation, international PNT needs and challenges, as well as dialogue with international PNT policy actors. It should be noted that the CGSIC meeting has been cancelled in 2025, and the US PNT Advisory Board charter has expired in April 2025 and has not been renewed.

From a defence perspective, the US engages in bilateral and multilateral cooperation to support navigation warfare (NAVWAR), spectrum protection, and PNT resilience. Through NATO and the Five Eyes partnerships, the DOD collaborates with allied militaries to share threat intelligence, coordinate PNT interference mitigation strategies, and conduct joint testing of assured PNT systems. Additionally, the collaborations also support the development of encrypted military signals and hardware for the GPS M-code.

3.2.7 US Summary

The US anchors its PNT strategy around GPS ownership and operational control, underpinned by joint civil-military governance model. Policy instruments such as Executive Order 13905 and Space Policy Directive-7 emphasise the protection and augmentation of PNT infrastructure, the need for complementary systems, and a robust approach to cyber and spectrum threats. The US also leads in fostering commercial innovation, with increasing exploration and testing of commercial and alternative capabilities. The National Executive Committee for Space-Based PNT, co-chaired by the US Department of Defense and Department of Transportation, oversees cross-government coordination. Within Defense, a tri-chaired PNT Oversight Council and the US Space Force manage military operations, including M-code capabilities.

3.3 European Union

Europe's current PNT policy is largely embedded within its broader civil space policy framework, such as the 2016 Space Strategy for Europe [55] and the EU Space Programme 2021-2027 [56], within which Galileo and European SBAS, known as the European Geostationary Navigation Overlay Service (EGNOS), act as a key satellite-based navigation system components. While there are no formal standalone EU PNT policies, the European Commission has released the European Radio Navigation Plan (ERNP) 2023, which is a reference document that provides relevant information on PNT systems, services, and resilience aspects [57].

3.3.1 EU approach to PNT

Europe presents a distinct approach to PNT, shaped by the cooperative nature of the European Union and the interplay between civil and defence priorities across 27 member states. Rather than pursuing purely national capabilities, the EU has focused on building shared sovereign infrastructure such as Galileo and EGNOS, while promoting resilience through coordination, regulation, and strategic investment. This approach is highlighted in the ERNP, which was originally released in 2018, with a more recent version being released in 2023.

Building on the foundation of PNT autonomy, Europe is now pursuing a comprehensive PNT system-of-systems approach to resilience. The ERNP 2023 underlines that no single technology can provide sufficient resilience for critical PNT users; instead, PNT services need to be diverse and integrated across a mix of space- and ground-based solutions. It calls for the EU PNT ecosystem to become a "system of PNT systems" in order to achieve the required robustness.

In practice, this requires coordination at the European level. The EU is putting in place a cross-sector framework for PNT resilience that encourages all stakeholders to augment GNSS with complementary measures. A key policy direction is to bolster Galileo and EGNOS services with Complementary PNT (C-PNT) solutions, that can act as local augmentations or backups to GNSS – notably to ensure continuity of timing for critical infrastructure like telecommunications and energy grids.

3.3.2 Governance

Currently, EU PNT governance only covers space-based PNT. The main bodies in charge of space policy in the EU are the European Commission (EC), European Space Agency (ESA), and European Union Agency for the Space Programme (EUSPA).

At the highest level, PNT policy and funding decisions fall under the remit of the European Commission. The Commission is responsible for defining priorities for the EU Space Programme, which includes Galileo, EGNOS, and emerging complementary PNT initiatives. Strategic direction is formalised through key documents such as the EU Space Programme Regulation, and the ERNP. Finally, defence activities are led by Directorate-General for Defence Industry and Space (DG DEFIS).

Day-to-day operational responsibility for Galileo and EGNOS resides with EUSPA, headquartered in Prague. EUSPA manages Galileo service provision, supports EGNOS operations in coordination with the European Satellite Services Provider (ESSP), and oversees user uptake, market monitoring, and secure applications such as Galileo PRS. EUSPA also works closely with ESA, which is responsible for system design, development, procurement, and R&D under the EU-ESA Financial Framework Partnership Agreement.

PNT-related R&D and innovation are also supported by the EU funded European GNSS Evolution Programme (EGEP) as well as separate Navigation Innovation and Support Programme (NAVISP), funded by voluntary contributions from ESA member states. ESA administers both elements. NAVISP plays a key role in testing novel PNT technologies, including quantum navigation, signal authentication, and multi-sensor integration while EGEP support upstream investment.

Overall, EU PNT governance is shaped by a multi-actor, multi-level structure designed to balance centralised policy coordination via the European Commission, operational delivery via EUSPA and ESA, national sovereignty and security over critical components like PRS, and collaborative innovation through programmes like NAVISP.

A simplified EU Space governance structure is shown in Figure 3 below.

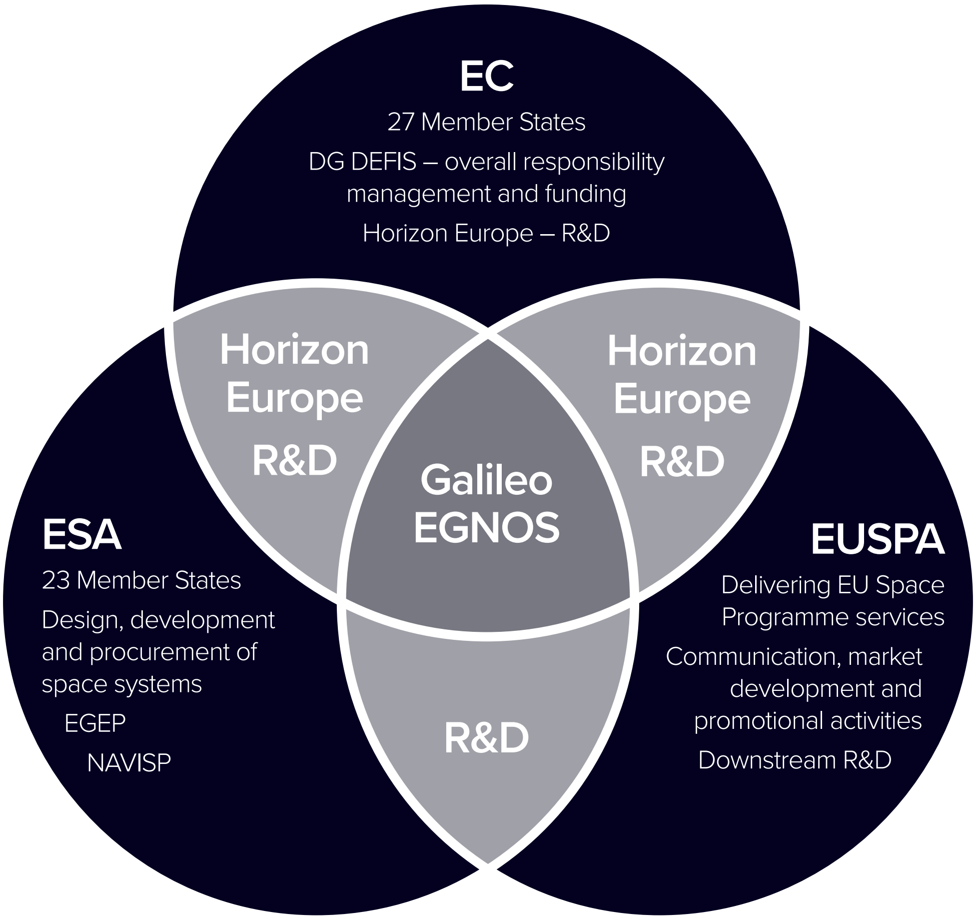

Figure 3. Simplified schematic of EU Space Governance.

3.3.3 Technological diversity

EU's approach to technological diversity is described in the ERNP. The ERNP breaks down PNT technologies into three categories. The main category consists of European GNSS (EGNSS), namely Galileo and EGNOS, which provide the backbone of PNT services in the EU. The second category consists of conventional PNT technologies, such as navaids to aviation and maritime industries. Whilst most of the technologies in this category are out of date and cannot provide the same level of service as GNSS, some remain relevant to provide resilience against RF interference and provide a complementary layer to PNT. Finally, the third category consists of emerging PNT services such as terrestrial, LEO PNT, quantum, etc., which can provide APNT services alongside GNSS [57].

Given the foundational importance of PNT to the effective operation of the EU's economy and society, ensuring resilient PNT capabilities is critical. While GNSS forms the backbone of current PNT services, true resilience demands a diversified approach that integrates a comprehensive blend of terrestrial and space-based technologies. No single system can provide the level of robustness required for users who depend on uninterrupted and reliable PNT data.

Achieving resilient PNT will also depend on robust monitoring mechanisms, particularly for detecting GNSS interference, and strong coordination frameworks linking GNSS providers, interference detection agencies, and national authorities. As such the ERNP recognises that the EU PNT ecosystem needs to become a "system of PNT systems" to achieve true PNT resilience [57].

3.3.3.1 Galileo and EGNOS

Galileo and EGNOS, collectively known as European GNSS, form the cornerstone of PNT services in Europe. Galileo provides global positioning, navigation, and timing with a civilian-controlled infrastructure, offering open signals as well as new services such as the Galileo High Accuracy Service (HAS) [58] and Open Service Navigation Message Authentication (OSNMA) [59], which can help against spoofing. Critically, Galileo also includes the Public Regulated Service (PRS) [60] – an encrypted navigation service for governmental-authorised users and sensitive applications that require high continuity. Access to PRS is tightly controlled and is limited to EU Member States and designated EU institutions (with the possibility for trusted partners via agreements).

Alongside Galileo, EGNOS provides regional SBAS services. EGNOS improves the accuracy and integrity of GPS and Galileo signals over Europe, and is vital for safety-critical applications such as aviation landing systems. Together, Galileo and EGNOS (in combination with GPS in many receivers) will remain the backbone of Europe's PNT services, but they are being continually strengthened.

3.3.3.2 Conventional PNT Technologies

The ERNP recognises an array of conventional PNT technologies including their main characteristics, as well as current status and whether the technology is still being used or modernised.

In conventional domain, various navaids technologies are described including Non-Directional Beacon (NDB), VHF Omnidirectional Radio Range (VOR), Distance Measuring Equipment (DME), Instrument Landing System (ILS), and Tactical Air Navigation System (TACAN) and longwave time and frequency distribution systems. Some of these techniques remain relevant, particularly in today's environment marked by increasing incidents of GNSS jamming and spoofing worldwide.

In the maritime domain, various flavours of LORAN are covered such as LORAN-C, enhanced LORAN (eLORAN) and differential LORAN (dLORAN), and it is noted that LORAN services are currently not provided in Europe.

Finally, in the timing domain, longwave time and frequency distribution systems and atomic clocks are covered. The development of optical clocks is noted as the main focus of research in the timing domain.

3.3.3.3 Emerging Technologies

Various emerging PNT technologies are covered in the ERNP including radio-based technologies such as terrestrial (pseudolites) and spaced based (LEO satellites); non-radio-based technologies, such as inertial and magnetic sensors; visual, LiDAR and radar-based technologies; quantum technologies; as well as mobile phone navigation for mass markets [57]. The development of optical clocks is noted as the main focus of research in the timing domain. It is noted that emerging technologies are designed to be a part of a combined offering of resilient PNT.

3.3.4 EU perspectives on sovereignty

Issues of sovereignty and control are fundamental to Europe's PNT strategy. The drive for European autonomy in navigation began with the Galileo program itself, an intentional decision to not remain indefinitely reliant on the US GPS. This desire for an independent system was validated during the development of Galileo by concerns that foreign GNSS might not always be guaranteed in times of political tension. By having its own fully fledged GNSS, Europe gains strategic assurance that it controls a primary means of PNT production.

Beyond satellite navigation, sovereignty extends to the complementary services. The EU's push to develop alternative PNT technologies has a strong sovereignty angle. The ERNP explicitly calls for the development of EU-based solutions to cover use cases requiring strategic autonomy.

In summary, sovereignty in Europe's PNT approach is about ensuring freedom of action. By investing in its own multi-layered PNT capabilities, Europe gains the freedom to rely on them when others might withdraw their services. The overall perspective is that Europe should never be in a position where it is "blind and lost" because another entity decided to deny service. Autonomous capability is the antidote to that risk [57].

3.3.5 EU civil-military strategic coordination in PNT infrastructure

The primary use of the current EGNSS is civilian, with most development efforts focused on civilian applications. Galileo is a civilian-operated GNSS managed under EU auspices, featuring secure governmental components such as the PRS, which can serve as a dual-use asset if necessary.

Security and defence operations depend strongly on space-based data and services, including dual-use technologies that serve both civilian and military needs. These systems help deliver secure, reliable, and high-performance services in a world with growing threats. The EU's Strategic Compass for Security and Defence identified space as a key area and led to the release of the EU Space Strategy for Security and Defence in March 2023 [61].

To support this, the EU funds research through programs like the EU Security Research and Innovation Programme and Horizon Europe (Cluster 3: Civil Security for Society), as well as earlier programs like Horizon 2020, FP7, and PASR [57]. Since 2004, over 700 projects have been supported. These programs encourage collaboration and focus on using PNT and GNSS technologies for security tasks such as law enforcement, border control, maritime safety, protecting critical infrastructure, and disaster response. Projects funded under Horizon Europe's Cluster 3 are required to use components of the EU Space Programme when developing relevant PNT solutions.

3.3.5.1 Defence Timing and Situational Awareness

For defence forces, assured timing and navigation are mission-critical enablers. Modern military operations require precise PNT information for command and control, battlefield awareness, targeting, and synchronisation of forces. From encrypted communications networks to guided weapon systems, nearly all military technology depends on reliable timing and positioning. Recognising this, European defence planners treat resilient PNT as essential to maintaining operational capability in contested environments. Robust timing is especially critical for network-centric operations: secure communications and data links rely on synchronised clocks, and any loss of timing (for instance due to GPS disruption) can degrade coordination.

To address this, Europe is enhancing its timing infrastructure in ways that will benefit defence and security users. An example is the proposed continental time distribution backbone using fibre optics: by providing an independent source of traceable, ultra-accurate time across Europe, military and civilian users could have a fallback timing reference if GNSS timing is lost. This would keep communications, radar systems, and databases aligned to the nanosecond, even under GPS/Galileo denial. In addition, many European nations maintain precise clocks or timing centres (often at national metrology institutes or military signal corps units) that can hold time autonomously for a period of time. Integrating these via the EU-wide network would create a resilient timing mesh that supports defence needs.

Additionally, European militaries are emphasising robust navigation techniques that can complement GNSS. This includes greater use of inertial navigation systems (accelerometers and gyroscopes) on vehicles, combined with map-matching or terrain reference navigation for cruise missiles and aircraft. While these are platform-specific measures, at a higher level the EU's system-of-systems approach is being shaped to provide multiple layers of PNT information to military users. In the field, a soldier or vehicle might soon have a multi-source PNT receiver that blends Galileo PRS, GPS M-Code (for those in NATO), signals from an eLORAN transmitter, and timing from a local 5G node – all integrated to present a single, highly reliable position/timing solution. Such capabilities will dramatically improve resilience of situational awareness for European defence forces, ensuring that even under sophisticated jamming or in anti-satellite scenarios, they do not lose their PNT capabilities.

3.3.5.2 Secure Receiver Development

Finally, Europe recognises that the resilience of PNT services is only as good as the receivers and user equipment that utilise those services. Even if multiple signals are available, the end-user device must be capable of acquiring, integrating, and using them securely. Therefore, a strategic focus has been placed on developing secure and robust PNT receivers, with key efforts include military-grade multi-system receivers, resilient mass-market devices, as well as secure certification and control.

By advancing secure receiver technology, Europe is fortifying the last mile of PNT. This user-centric perspective ensures that the benefits of the system-of-systems approach are actually realised on the ground. A diverse PNT infrastructure is only effective if users have access to equally sophisticated equipment to utilise it. Europe's policies and funding reflect this full-stack approach, covering space infrastructure, terrestrial systems, and end-user technology in a coordinated fashion.

3.3.6 International Collaboration for PNT Resilience

While fostering sovereign capabilities, Europe also actively collaborates internationally to improve resilience and interoperability of PNT on a global scale. The European Union collaborates with various countries and international organisations to support satellite navigation systems, particularly Galileo and EGNOS. Non-EU countries like Norway, Iceland, and Switzerland participate in components of the EU Space Programme through the European Economic Area (EEA) or dedicated GNSS Cooperation Agreements. The EU has also signed agreements with ASECNA (for aviation-focused satellite services in Africa), South Korea, and Morocco, covering areas such as spectrum protection and GNSS development.

A cornerstone of EU international GNSS cooperation is its long-standing partnership with the United States, formalised in a 2004 agreement on GPS and Galileo [62]. This agreement ensures signal interoperability, promotes fair trade, and establishes three working groups on radio compatibility, market access, and next-generation system development. The latter includes subgroups addressing advanced R&D, service provision strategy, and system resilience to threats like interference.

Additionally, the EU is active in global GNSS coordination through the UN-backed International Committee on Global Navigation Satellite Systems (ICG), where it promotes compatibility and interoperability across providers. The EU also works through the International Telecommunication Union (ITU) to safeguard radio spectrum for GNSS use, and participates in multilateral bodies such as the International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO) to shape satellite navigation standards and policy [57].

3.3.7 EU Summary

The European Union is advancing a federated "system of PNT systems," leveraging the Galileo navigation satellite system and regional augmentation system (EGNOS), alongside complementary technologies like fibre-optic timing and future Low Earth Orbit platforms. Governance is distributed, but coordinated through the European Commission, ESA and EUSPA. The EU model prioritises strategic autonomy through shared sovereignty and tightly regulated secure services, while promoting interoperability and civil-military alignment.

3.4 Canada

Canada does not have a federal PNT policy or strategy. Canada's approach to PNT resilience includes efforts led by multiple federal departments and agencies that reflect their respective mandates in the context of PNT resilience. The federal departments and agencies with mandates relevant to PNT issues include the fifteen that participate in the Canadian PNT Board, which supports interdepartmental coordination on civil PNT issues. Canada does not have ownership of its own space PNT system, and for civil applications, it relies heavily on GNSS – especially GPS, as well as WAAS, which has coverage across Canada.

Canada's Department of Defence leverages a number of programs to advance research for public safety and defence domains, including research into alternative PNT solutions such as quantum technologies and inertial navigation. Coordination on technology development between civilian and military sectors remains limited. Strong international collaboration, particularly through Five Eyes, AUKUS, and bilateral agreements, underpins Canada's defence related PNT efforts, with a focus on shared situational awareness, technology development, and counter-PNT initiatives.

3.4.1 Canada's approach to PNT

Canada's use of PNT has historically relied on foreign GNSS signals. Canada does not own or operate a national GNSS. However, Natural Resources Canada (NRCAN) operates several GNSS ground station networks, anchored by the Canadian Active Control Station (CACS) network. In Canada, no single federal department has an exclusive mandate for GNSS and PNT application or policy development. Instead, many federal departments and agencies have mandates relevant to various aspects of GNSS, PNT, and PNT resilience issues. As such, a group of interested departments and agencies established the Canadian PNT Board, originally Federal GNSS Coordination Board (FGCB), to serve as a central point of contact for federal PNT issues and a hub for information exchange with foreign partners on civilian PNT matters. The PNT Board was established in 2011 under a formal Memorandum of Understanding (MOU) between departments. There have been four sequential MOUs to continue this structure. The PNT Board is governed by its Steering Committee which is formed from executive level representatives of the seven federal departments and agencies that are Sponsors of the PNT MOU. By coordinating and building consensus at the federal level, the PNT Board aims to foster greater PNT knowledge, promote resilient PNT uses and support Canada's economic growth.

A Canadian PNT Office was established to consolidate PNT-related efforts, conduct strategic analysis and liaise across government. It also acts as the formal Canadian interface into the federal government on PNT matters.

To improve understanding of the PNT issues, Canadian federal departments and agencies have undertaken assessments of PNT vulnerabilities and impacts. Notably, the PNT Board commissioned an Economic Value of GNSS-Based PNT study (conducted by Ernst & Young in 2022) to quantify how deeply Canada's economy and society rely on GPS/GNSS [63]. In parallel, an Analysis of Canadian GNSS Interference Detector Data was completed in 2023 to understand the frequency and nature of GPS interference events domestically [64]. A PNT Risk Assessment and Risk Mitigation Assessment Project examined PNT risks across Canada's ten designated critical infrastructure sectors [65]. This project, led by Innovation, Science and Economic Development (ISED) on behalf of the PNT Board, solicited input from sector stakeholders (such as energy, finance, transportation, safety, and telecom industries) on how a loss of PNT would affect their operations and what mitigations are in place.

By coordinating and sharing information at the federal level, the PNT Board aims to foster greater PNT knowledge, promote resilient PNT uses and support Canada's economic growth.

3.4.2 Governance

Canada's PNT governance model is defined by decentralised coordination rather than centralised authority. While the Canadian PNT Board serves as the main interdepartmental mechanism for aligning policy, commissioning studies, and engaging with international partners, specific efforts remain distributed across departments in alignment with their specific mandates. This governance structure reflects Canada's regulatory and policy authorities – pragmatic and collaborative, with responsibilities aligned to departmental mandates. There is no cross-sectoral policy that oversees Canada's national PNT activities, and there is no over-arching governance structure for all PNT-related initiatives or matters. Instead, the Department of Defence addresses matters related to defence activities and the Canadian PNT Board makes recommendations to support PNT related policy development in respective federal departments and agencies.

3.4.3 Technological Diversity

Various federal departments and agencies are aware of efforts around the world towards a multi-layered, multi-technology approach to facilitate PNT resilience. To that end, departments and agencies are exploring a broad suite of complementary systems tailored to Canada's vast and diverse geography. Both space-based and terrestrial technologies are being studied.

In terms of space-based systems, multi-GNSS remains the core of Canada's civil positioning needs, supported by regional augmentation from the US-based WAAS. Some performance evaluations of WAAS in its maritime domains, including the Arctic, have been conducted to assess its suitability for navigation in northern waters [66].

On the terrestrial front, Canada previously operated a Differential GPS (DGPS) service through the Canadian Coast Guard, but this was decommissioned in 2022 due to technological obsolescence. More recently, Canada has partnered with Germany to investigate the potential of Medium Frequency Ranging (MF R-mode), which uses terrestrial radio signals to support maritime navigation, particularly in GNSS-challenged environments [67].

Canada's path forward on PNT diversity is unclear. It could potentially consider investments in a portfolio of complementary systems if direction can be taken from studies such as those for non-GNSS maritime navigation, funding through existing programs for research into alternative PNT technologies, and engagement with international partners. In some cases, science and technology cooperation frameworks are being leveraged to share knowledge and explore emerging PNT concepts.

3.4.4 Canada's Perspective on PNT sovereignty

Canada had made no official statement related to its perspective of PNT sovereignty in the context of civil PNT applications. As noted previously, Canada does not own or operate its own GNSS or other space-based PNT system. For a country of Canada's size and resources, full control over space-based navigation may not be a practical goal. Within defence circles, there's a recognition of the need for assured access to critical PNT services, especially through encrypted signals.

Defence leads much of the conversation around PNT resilience. Research into counter-PNT, electronic warfare, and cyber resilience is well advanced, supported by strong ties to international frameworks such as Five Eyes and AUKUS. These partnerships play a crucial role in technology advancement as well as building situational awareness and aligning strategies across allied nations.

3.4.5 Canada's Civil-Military Strategic Coordination in PNT Infrastructure

Ensuring PNT resilience is a shared responsibility that links civil and military domains. The infrastructure that delivers PNT services and the strategies to protect it must be coordinated between civilian agencies and the defence. While currently Canada does not have a holistic PNT policy across government, collaboration and information between the civil and defence aspects happens due to the long-standing collaborative relationship of the Canadian PNT Board.

On the military side, Canadian armed forces are looking at encrypted GPS solution (M-code) as the primary means of obtaining PNT on the battlefield. The military are also looking at alternate PNT signals for various back up options, however at this stage they are not ready to be incorporated into policy.

In terms of infrastructure, many PNT resilience measures are inherently dual-use, meaning they can support both civil and military applications. For instance, if Canada deployed a terrestrial system as a GPS backup, that system can broadcast a signal usable by anyone with an appropriate receiver, for example civilian maritime navigation, while also providing the military a robust navigation signal for home defence operations.

Another aspect of coordination is in standards and equipment. The military often has more stringent PNT requirements (e.g., higher integrity and anti-spoofing for weapon guidance), which drives development of advanced technologies, such as encrypted M-code GPS receivers, anti-jam antennas, inertial systems in platforms, etc.

In summary, civil-military coordination could multiply the effectiveness of Canada's PNT resilience measures. By sharing information, co-developing infrastructure, and aligning strategies, the defence sector and civilian sectors could avoid working at cross purposes or duplicating efforts. Canada's defence leadership has an important role to play advocating for resilient PNT in national policy forums, investing in technologies that benefit broader society, and ensuring that military requirements are leveraged to deliver dual-use capabilities.

3.4.6 International Collaboration for PNT Resilience

Canada's approach to PNT resilience is strongly underpinned by international collaboration. As a country without its own sovereign satellite navigation system, Canada has long prioritised strategic partnerships to access to PNT services. This includes both bilateral cooperation with the United States and multilateral engagement through alliances such as the Five Eyes, AUKUS, NATO, and ICAO.

Canada relies heavily on GPS for a multitude of civil PNT functions, as well as on the US operated WAAS for regional augmentation. Canada also from time-to-time participates in the CGSIC, which enables technical exchange on user needs. Within the Five Eyes intelligence and defence alliance, Canada collaborates closely on situational awareness, threat monitoring, and resilience strategies.

Canada is also an active participant in global navigation forums. It contributes to ICAO efforts on aviation navigation standards, particularly in relation to SBAS, and has supported maritime PNT guidance under the IMO. Additionally, Canada engages in R&D cooperation with partners such as Germany in MF R-mode trials for maritime GNSS backup.

By aligning with like-minded partners and contributing to joint innovation, Canada ensures it remains integrated into secure, high-assurance navigation ecosystems that meet both civil and defence needs.

3.4.7 Canada Summary

Canada offers a pragmatic model built around trusted partnerships, notably with the United States, and evidence-based assessments of PNT risk. While lacking sovereign GNSS assets, Canada is investing in alternative PNT research and fostering coordination through its interdepartmental PNT Board.

3.5 Japan

3.5.1 Japan's Approach to PNT

Japan's approach to PNT is centred on the Quasi-Zenith Satellite System (QZSS), a regional satellite navigation constellation known as "Michibiki." Rather than developing a full global GNSS from scratch, Japan invested in QZSS to augment and complement GPS, thereby improving coverage and reliability of satellite navigation over Japanese territory and the Asia-Oceania region. QZSS was conceived to address GPS performance gaps in urban canyons and mountainous terrain by ensuring at least one satellite is near zenith over Japan at all times. By design, QZSS is fully compatible with GPS and other GNSS, enabling integrated use for improved precision and availability.

The system officially began service in November 2018 with a four-satellite constellation, providing basic PNT signals interoperable with GPS, as well as augmentation services for higher accuracy. The current plan is to expand the constellation to seven satellites within the next two years, with a long-term goal of growing to eleven satellites by the late 2030s to enhance resilience and provide more stable positioning [68]. This expansion, targeted for completion by the late 2030s, reflects a commitment to long-term PNT resilience.

Japan has explicitly framed QZSS as critical national infrastructure for positioning, navigation, and timing. The government elevated QZSS as a top priority under its space policy, seeing it as a foundation to boost industrial competitiveness, support daily life services, and strengthen Japan's international presence in PNT [69]. The system's goals include providing stable, uninterrupted PNT services "in all locations at all times" within Japan's vicinity. It delivers not only navigation signals, but also advanced GNSS augmentation services, including regional SBAS, which in Japan is called MTSAT Satellite-based Augmentation System (MSAS), and an Emergency Warning Service (EWS) capable of sending text alerts directly to mobile phones in the event of impending disasters such as earthquakes or tsunamis. The EWS is developed jointly with Europe who provides a similar service from Galileo satellites [70].

These features illustrate Japan's holistic approach to PNT, treating it as a societal infrastructure that underpins everything from transportation and precision agriculture to disaster management and financial systems.

3.5.2 Governance

Japan's PNT governance is a cross-government effort coordinated at the Cabinet level. The Cabinet Office's National Space Policy Secretariat (NSPS) oversees the QZSS program and broader PNT strategy, acting as a central hub to align various ministries' efforts. This centralised oversight was established following the 2008 Basic Space Law, which recognised space (including PNT) as a matter of national strategy requiring whole-of-government coordination [69].

Under NSPS leadership, which oversees the program management and budget coordination for QZSS and space policy integration, multiple ministries and agencies contribute to PNT implementation and services. Japan Aerospace Exploration Agency (JAXA) is responsible for technical development, satellite launches, and initial operation of QZSS satellites. Ministry of Land, Infrastructure, Transport and Tourism (MLIT) oversees the applications of PNT in transportation including management of MSAS for the aviation sector. Ministry of Internal Affairs and Communications (MIC) looks after spectrum management for PNT signals and support of communication infrastructure for timing dissemination. The Japan PNT governance is shown in Figure 4 below [71].

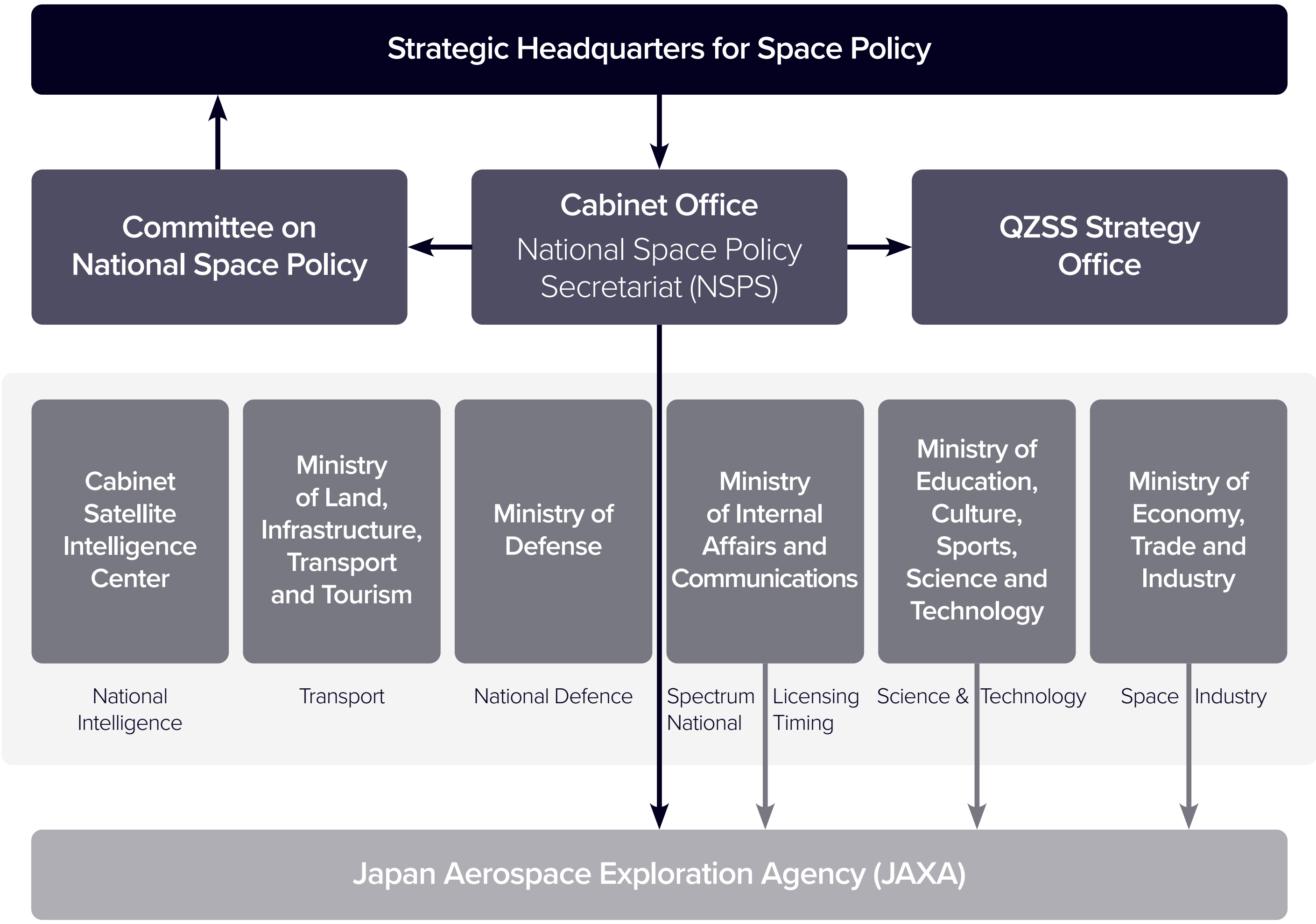

Figure 4. Japan PNT Governance.

Notably, Japan does not have a single "PNT regulator" or dedicated office akin to the UK's PNT Office or Canada's PNT Board. Instead, it uses inter-agency committees and the Cabinet Office to harmonise efforts. This governance model ensures that both civilian and defence considerations are integrated – while civilian ministries handle most operational aspects of QZSS, the national security community is consulted to ensure PNT policy supports defence needs. All told, Japan's governance approach is one of coordination rather than regulation, uniting diverse agencies around a common goal of resilient PNT, under high-level strategic guidance from the Cabinet Office.

3.5.3 Technological Diversity

Most of the PNT technology focus in Japan is centred around satellite navigation. The QZSS system itself exemplifies diversity through its multiple signal types and services. In addition to standard GPS-compatible signals, QZSS transmits an L-band signal (L6D) carrying high-precision correction data, which enables the Centimeter Level Augmentation Service (CLAS) [72]. By deploying such advanced augmentation technology, Japan is ensuring that critical applications (e.g., autonomous vehicles, precision agriculture, surveying, etc.) have access to much more accurate and robust positioning than legacy GPS alone can provide.

Notably, Japan's approach to PNT diversity also extends to signal security and robustness. QZSS has begun broadcasting the Quasi-Zenith Navigation Message Authentication (QZNMA) on its L6E signal, an authentication service to counter spoofing by allowing receivers to verify that signals (including those from other GNSS) are genuine [68].

Beyond QZSS, JAXA is actively exploring the development of a Low Earth Orbit (LEO) PNT constellation as part of its long-term strategy to enhance positioning accuracy, availability, and resilience. The proposed LEO-based augmentation system aims to deliver a more advanced GNSS augmentation service by providing faster signal acquisition, stronger signal strength, and reduced latency. By leveraging the advantages of LEO orbits and Japan's expertise in GNSS augmentation, JAXA's initiative could significantly improve positioning performance across the Asia-Pacific region and offer a sovereign, complementary capability to traditional MEO-based GNSS services [73].

In the timing domain, the National Institute of Information and Communications Technology (NICT) maintains Japan Standard Time with an ensemble of atomic clocks and distributes it via multiple channels, such as fibre optic links, LF radio and internet network time protocol (NTP). This provides trusted time synchronisation for telecommunications, finance, and power grid systems independent of GPS timing. Research programs are also exploring next-generation PNT technologies. For instance, NICT has pioneered optical clock technology and tested two-way satellite time transfer with QZSS and NASA to improve precision timing links between Japan and overseas timing centres [74].

In summary, Japan's PNT architecture is heavily centred around satellite technologies and terrestrial timing dissemination, where QZSS satellites provide an overlay to GPS, augmented by ground infrastructure and emerging technologies. This layered approach is intended to guarantee that position and timing information remains available and accurate under a wide range of conditions. However, it should also be noted that Japan's focus on satellite-based solutions means that terrestrial navigation alternatives remain underdeveloped, leaving a potential vulnerability in the event of electronic warfare in a conflict scenario.

3.5.4 Japan's Perspective on PNT Sovereignty

Japan's view of PNT sovereignty is pragmatic and closely tied to the concept of assured access. Unlike some regions (e.g. Europe with Galileo), Japan did not see a need to completely replace or duplicate GPS. Instead, it regards sovereignty in PNT as the ability to guarantee essential PNT services for itself, on its own terms, even if external systems become unreliable or unavailable. The development of QZSS reflects this nuanced stance. By building a regional satellite system under Japanese ownership and control, Japan gains a measure of independence and redundancy without having to field a global GNSS constellation. In effect, QZSS grants Japan partial PNT sovereignty, i.e. the system can operate independently or in tandem with GPS, and Japan alone controls its satellites, signals, and data. This means in a contingency, Japan could rely on QZSS to continue providing position and timing to domestic users, mitigating an exclusive reliance on foreign GNSS.

In this context, sovereignty also means data and service control. Through QZSS's high-precision services, Japan controls the distribution of augmentation within its territory and can ensure those services meet national requirements (e.g., nationwide cm-level navigation for Japanese defence and emergency services). Moreover, by managing its own PNT infrastructure, Japan can enforce domestic security policies, such as shutting off certain signals in wartime or customising them for authorised users.

In practical terms, Japan seems comfortable with a hybrid sovereignty model: GPS is seen as a “friendly” backbone that Japan helps to sustain and protect internationally, while QZSS serves as Japan’s assured layer of PNT availability and quality. By 2023, the Basic Plan on Space Policy explicitly linked space security and autonomous capabilities, emphasising that maintaining autonomous access to critical space systems (including PNT) is essential for national security and economic stability [72]. Japan’s perspective is that it must never be left “blind”, even if geopolitical situations change, a goal it seeks to achieve through QZSS expansion, multi-GNSS interoperability, and secure control of PNT data. This approach to PNT sovereignty balances independence with alliance cooperation, ensuring freedom of action in PNT without duplicating effort where allies already provide reliable services.

3.5.5 Japan’s Civil-Military Strategic Coordination

Although QZSS is a civilian-operated system, Japan’s civil and defence sectors coordinate closely to maximise PNT resilience for national security. The dual-use nature of PNT is well recognised – the same satellites and timing infrastructure that guide civilian applications also underpin military operations. Japan’s military forces work in tandem with civil agencies to ensure PNT infrastructure meets defence needs and that there is no single point of failure. One example of this coordination is the hosting of US defence payloads on QZSS satellites, a recent development that required deep cooperation between Japan’s Cabinet Office and the Ministry of Defense [75]. In early 2024, Japan launched QZS-6 satellite carrying a USSF sensor suite for space domain awareness, piggybacking on Japan’s PNT satellite [76]. While the payload serves US and allied military interests, its presence on QZSS reflects Japan’s willingness to integrate military requirements (space surveillance in this case) into its civilian space infrastructure. This mission was lauded as a historic milestone in aligning national security space efforts, and it inherently required joint oversight. The success of QZS-6’s hosted payload indicates that Japan can flexibly use its PNT assets for both civil and military purposes with proper coordination.

On the domestic front, the Ministry of Defence ensures it has representation and input in national PNT policymaking. The integration of space policy under the Cabinet Office means that MoD officials participate in committees that shape programs like QZSS, so that features important to defence (e.g., anti-jamming capabilities, encryption, or rapid recovery protocols) are accounted for in system design. This ensures that military users are equipped with multi-GNSS, resilient receivers that can fall back on QZSS or other inputs if GPS is compromised. Japanese industry has also been involved in developing advanced receivers and antennas (with anti-jam/spoof features) for defence to harden end-user equipment across both civil and military domains [69].

Overall, Japan’s civil-military PNT coordination can be characterised as shared infrastructure, distinct roles. The same QZSS satellites and timing networks service everyone, but civilian agencies handle routine operations and public services, while defence authorities focus on protecting these assets and tailoring their use for security missions. The synergy is evident, for example, QZSS EWS (run by civilian agencies for disaster warnings) could equally broadcast military crisis communications if conventional channels failed. And conversely, the defence force’s space surveillance of the QZSS constellation directly benefits the civil operators by alerting them to potential hazards or interference. Such interplay means Japan’s PNT system is effectively a dual-use capability. The government acknowledges this by funding PNT enhancements that serve both communities, such as the QZSS upgrades and new ground monitoring stations, under a national security justification as well as a civil infrastructure one [68].

3.5.6 International Collaboration for PNT Resilience

International collaboration is a cornerstone of Japan’s PNT strategy. Given that Japan’s PNT backbone includes foreign systems (primarily GPS), ensuring those systems’ robustness and interoperability is in Japan’s national interest. Thus, Japan has long-standing cooperative arrangements with the United States and actively engages in multilateral forums to enhance global PNT resilience. The US-Japan partnership on GNSS is particularly deep – the two countries have signed a “Joint Statement on Cooperation in the Use of the Global Positioning System” back in 1998 [74]. Through this mechanism, Japan ensured that QZSS would be fully interoperable with GPS (e.g., using the same reference frame and signal structures), and the countries coordinate on issues like GPS modernisation, QZSS expansion, and spectrum protection.

The collaboration also extends to infrastructure sharing, with the United States hosting QZSS monitoring stations in Guam and Hawaii to support expanded coverage. The two countries also cooperate on time synchronisation between their respective national timing authorities. This mutual support was acknowledged in a joint statement, where both governments affirmed that close cooperation in satellite navigation contributes to the “peaceful development of the Asia-Pacific region” and agreed to pursue compatibility among all their systems [74].

Japan also actively collaborates with other partners to reinforce PNT resilience regionally. With Australia, Japan has conducted joint trials and dialogues on satellite navigation. Notably, Japanese QZSS satellites were used in Australia to test the EWS, broadcasting disaster alerts to mobile devices as part of an EU-Japan initiative on GNSS safety services [78]. The test in Melbourne demonstrated interoperability between QZSS and potential Galileo-based services, and showed how QZSS could assist Australia and other Asia-Pacific countries with emergency messaging. Australia and Japan have also discussed cooperation on augmentation systems; the QZSS footprint reaches parts of Australasia, offering an opportunity for Australia's geospatial community to leverage Japanese high-precision signals [77].

In Southeast Asia, Japan engages through the Multi-GNSS Asia (MGA) framework and bilateral projects, bringing ASEAN countries, India, Australia and others together to promote usage of multiple constellations including QZSS. Through these forums, Japan provides technical training, supports pilot projects, and aligns QZSS services with regional user needs. One example includes demonstrations of QZSS-based precision positioning for agriculture in Australia [79]. This diplomacy through PNT strengthens regional resilience by enabling neighbouring countries to access reliable positioning and EWS information, while also extending the influence of Japan's system.

On the global stage, Japan contributes to setting PNT best practices and standards. It is an active member of the International Committee on GNSS (ICG) under the United Nations, collaborating with the EU, India, China, and others to ensure interoperability and promote robust signal provisions worldwide. Japan's involvement in ICAO and IMO helps shape international requirements for navigation integrity and backups drawing from its experience with QZSS, MSAS, and marine DGPS. Moreover, as threats like spoofing and jamming grow, Japan has joined allies in information-sharing on PNT threats. Within the Quad and other security dialogues, Japan has emphasised the need for resilient space-based timing and navigation as part of collective security in the Indo-Pacific [80].

In essence, Japan views international collaboration as indispensable to PNT robustness. No single country's system is infallible, so Japan works closely with trusted partners to create a more redundant and secure PNT environment. By aligning with the US and sharing technology with friends in Asia-Pacific, Japan not only secures its own PNT needs, but also contributes to a network of systems that collectively bolster resilience for all participants. This collaborative ethos ensures that Japan stays at the forefront of PNT developments and that it can call upon allies' support to mitigate crises affecting positioning or timing. Japan's strategy thus combines sovereign capability with alliance-based interoperability, reinforcing both its autonomy and the resiliency of the broader PNT landscape on which it depends.

3.5.7 Japan Summary

Japan's PNT governance is led at the executive level by the Cabinet Office, which oversees enabling functions of strategy, policy, research and development, and spectrum management, ensuring coordinated, whole-of-government oversight. Japan's QZSS demonstrates regional augmentation and GNSS complementarity. Designed to enhance GPS performance over Japan and neighbouring regions, QZSS integrates with other GNSS systems while offering unique timing and messaging capabilities, ensuring that both defence and civilian benefits are maximised. Japan positions PNT as critical infrastructure and incorporates space into its national security strategy, including civil-military integration for resilience.

4 RELEVANCE TO AUSTRALIA

This chapter presents observations about Australia's governmental approach to PNT and discusses the relevance of international PNT approaches that may benefit Australia. It unpacks Australia's dependence on GPS, explores technological options that may provide PNT diversity, highlights the need for a coordinated national approach as well as a national coordinator, and discusses the civilian-military interactions of PNT in Australia.

4.1 Australia's current approach to PNT

4.1.1 Australia's narrow focus on GPS augmentation

Australia is almost entirely dependent on GPS for its PNT needs. On the civil side, significant government investment has been made in augmentation services, being the development of SouthPAN, Australia's and New Zealand's SBAS [81], and supporting geodetic ground infrastructure through the Positioning Australia program [82]. SBAS enhances the accuracy and reliability of PNT services for civilian applications including aviation, but it does not offer any additional resilience against jamming and spoofing attacks.

In the defence domain, Australia benefits from its close alliance with the US, including access to M-code military-grade receivers that can make use of encrypted GPS signals [83]. This provides access to hardened PNT services, assuming the necessary M-code compatible receivers can be deployed on warfighting platforms. While options such as GPS III and M-code capable systems offer improved resilience, the US rollout of M-code receivers has faced delays [84], leaving Australia exposed to potential disruptions. In essence, Australia continues to rely on GPS as the foundational, and perhaps only, layer of its PNT architecture.

4.1.2 Mainstream national narrative shifting from GNSS to PNT

Traditionally, Australia's national focus has centred on enhancing GNSS-based positioning accuracy for civil applications, including safety-of-life services through initiatives like SouthPAN. Earlier strategies, such as the Australian Geospatial Consortium's 2015 Australian Strategic Plan for GNSS [85], primarily framed PNT in terms of GNSS capability. However, the national narrative has since broadened to recognise PNT as a multi-layered resilience challenge that extends beyond GNSS alone. This shift is reflected in more recent initiatives, including the Australian Space Agency's (ASA) PNT roadmap [86], and Defence's JP9380 "Assured PNT in a Contested Environment" program [87].

However, the PNT roadmap and JP9380 efforts have either stalled or struggled to gain sustained government momentum in recent years. The ASA, with a limited mandate as a coordination and regulatory agency, has never formally published its PNT roadmap. The Defence JP9380 program initially signalled a strong intent, seeking industry proposals to help establish a NAVWAR centre modelled on the US JNWC, alongside a multilayered PNT architecture and technology roadmap [88]. However, the program has quietly been sidelined, while the 2024 National Defence Strategy and associated Integrated Investment Program diverted funding towards other priorities.

As an interim measure, a Joint PNT Directorate has been established within the Defence Joint Capabilities Division since July 2024. Its scope is formally to *"…establish foundation PNT capabilities to support multilayered, multi-domain PNT alternatives (including Space based systems beyond GPS…"* [89]. To date, it has primarily focused on the rollout and operational testing of M-code capabilities in coordination with its US counterpart JNWC [90]. Overall, Defence has also increased activity to use emerging, commercially-developed technologies for quantum-enabled precision navigation and timing (discussed further in Section 4.3).

In contrast, the research and industry sectors have shown greater activity in developing PNT technologies while raising awareness of the associated risks of loss of PNT. However, without a clear commitment from government to act as an anchor customer for these technologies, these efforts face barriers to scaling and broader user adoption. This gap highlights the need for stronger alignment between policy, investment, and industry capability to de-risk Australia's significant PNT vulnerabilities.

4.1.3 Lack of recognition of PNT as a strategic threat

Unlike the UK, Australia does not maintain a single, consolidated national risk register. Instead, risk and mitigation frameworks are distributed across various government departments, each focused on sector-specific or domain-specific concerns. No single entity is responsible for overseeing PNT or assessing PNT-related risks. While the US and UK have identified PNT disruption as a critical risk to national resilience, Australia has not yet assigned the issue the same level of strategic priority or visibility within national policy frameworks.

Existing guidance, such as the Critical Infrastructure Annual Risk Review [91] issued by the Department of Home Affairs (DHA) Cyber and Infrastructure Centre (CISC), only briefly mentions PNT, and then only in the context of natural hazards like space weather. This narrow framing overlooks other hazard vectors including supply chain, personnel, and cybersecurity hazards.

CISC has also issued a Fact Sheet for Positioning, Navigation and Timing [92] that touches on some of these broader hazard vectors. However, the guidance is preliminary and lacks detailed mapping of sectoral dependencies on PNT. As a result, PNT disruptions in Australia continue to be deemed "less plausible" in cross-sector risk prioritisation [93]. This severely underrepresents the immediate and cascading impacts of PNT disruptions to critical infrastructure, especially given the dependency on precise time synchronisation across the energy, transport, finance, communications, and defence industry sectors. A scenario-based exploration by FrontierSI on PNT disruptions to Defence operations demonstrates the breadth and severity of these impacts, highlighting risks that extend well beyond Defence warfighting operations to pose societal-scale national security threats [94].

4.2 Recommended PNT Governance

4.2.1 Current State

Key government departments involved in PNT activities include Geoscience Australia, the DHA CISC, the Australian Maritime Safety Institute (AMSA), the Department of Defence, Airservices Australia, the Civil Aviation Safety Authority (CASA), the National Measurement Institute (NMI), Australian Geospatial-Intelligence Organisation (AGO) and Department of Infrastructure, Transport, Regional Development, Communications and Arts (DITRDCA). Their respective roles are summarised in the 2022 *State of Space Report* [95], and explored in further detail in FrontierSI's 2024 report *A Time and A Place for Resilience* [96]. Despite PNT being a critical enabler of critical infrastructure services, national security, and defence, and despite our vulnerable dependence on GPS, Australia lacks a cohesive national PNT policy framework.

Achieving "Resilient PNT" is not solely a technology challenge; it also requires a robust governance framework. The US has a devolved governance structure, with responsibility for PNT distributed across multiple departments and with distinct roles for civilian and defence applications. The UK and Canada have established a dedicated National PNT Office and centralised PNT Board respectively, to provide strategic oversight, coordination, and a central point of contact related to civilian and federal PNT. Japan has elevated PNT governance to the highest level, with strategy and coordination led directly by the Cabinet. In contrast, Australia lacks a comparable whole-of-government governance model, and lacks a national PNT policy or framework.

Geoscience Australia is widely recognised as the de facto authority for PNT. It leads the government's PNT Working Group that draws together key Australian Government agencies involved in PNT to advise the Australia's Space Coordination Committee [97]. However, GA's own remit is primarily focused on GNSS-related activities and its Positioning Australia program, which does not necessarily reflect a whole-of-nation evolving PNT risk landscape. Additionally, activities of the PNT Working Group remain low in terms of visibility to the public and appear fragmented across government.

4.2.2 Proposed PNT Governance Structure

To coordinate PNT efforts effectively, including in the design of a national PNT framework, Australia should consider establishing a national cross-government PNT coordination body, similar to the UK and Canada. Establishing a national PNT Office would provide strategic leadership and support the development of an officially recognised national framework or roadmap. However, such a body must be more than just a coordinator. To be effective, it must have the authority, mandate, and resourcing to deliver outcomes.

An indicative PNT governance approach is proposed in Figure 5. The proposed PNT office could be embedded within either the Department of Industry, Science and Resources (DISR), DHA, or established as a cross-departmental entity, to ensure coherence and accountability across civil and military domains. Here, DISR is recommended for the following reasons:

- International alignment: This model reflects governance approaches in the UK and Canada, where PNT responsibilities within the UK Department of Innovation, Science and Technology, and Innovation, Science and Economic Development Canada portfolios respectively. Like Australia, these countries do not operate their own GNSS constellations, and would take a sovereign approach through other PNT capabilities. Adoption of a similar governance model would also simplify coordination with international counterparts.
- In-portfolio governance model: In the first instance, it is recommended that the PNT Office be embedded within an existing Division of DISR [98], rather than established as a standalone agency or statutory authority. This would ensure sufficient resourcing, strategic alignment, and integration with key policy, strategy and coordination areas within DISR, including with the Industry and Commercialisation function.

- Technology and Digital alignment: The Technology and Digital division within DISR is a strong candidate, given that most if not all disruptions to PNT, whether due to cyber, natural, physical, personnel, supply chain hazards, ultimately manifest as disruptions to data and information services, which cascade across dependent sectors, including Defence. Notably, the Technology and Digital division is responsible for national AI policy and governance, which similarly to PNT has utilisation across all sectors of the economy.
- Science alignment: The Science division within DISR is another viable option, offering a natural home for roadmap development and strategic coordination of alternative and sovereign PNT technologies, including quantum.
- Portfolio coherence: DISR also leads national efforts in Sovereign Capability and Supply Chains, as well as Commercialisation policies.

A potential risk of embedding the PNT Office within either the Science or Technology and Digital divisions at DISR is that PNT may be framed as a technological capability, rather than through the lens of user resilience (discussed further in Section 4.3.3). This underscores the importance of the PNT Office maintaining active engagement with other government departments to ensure visibility of user-level vulnerabilities and operational dependencies across diverse sectors.

In the governance schematic, the PNT Office would:

- Provide strategic oversight and policy alignment across civil and defence domains;
- Lead development of an officially-recognised national PNT framework, roadmap, or plan;
- Improve national situational awareness of PNT risks and dependencies;
- Support coordinated investment in PNT resilience, covering a range of agreed systems within the national PNT framework, roadmap, or plan;
- Serve as the initial point of contact for international engagement on PNT resilience;
- Coordinate with the “operational leads” for delivering on key capabilities within the PNT framework, including Defence.

Operational leads would include for example:

- Department of Defence – responsible for NAVWAR capabilities and overall military PNT resilience;
- Department of Home Affairs – coordinating critical infrastructure PNT resilience and national risk management;
- Geoscience Australia – leading national positioning, geodesy and augmentation efforts;
- National Measurement Institute – leading national timing services and standards;
- Australian Geospatial-Intelligence Agency – lead the geospatial and geodesy domains for Defence and the National Intelligence Community;
- Airservices Australia and the Australian Maritime Safety Authority – managing aids to navigation in the aviation and maritime domains respectively;
- Supported by cross-government committees such as the PNT Working Group and the Space Coordination Committee.

This list is not an exhaustive analysis on which government agencies include PNT functions as part of their operations. Rather it provides an indicative mechanism for structuring national PNT governance. This model currently appears department-centric, however a national PNT roadmap with objectives, and outcomes would help frame governance in a more initiative-centric approach. Then operational leads can be designated based on their role in achieving national outcomes framed within a national PNT framework or roadmap.

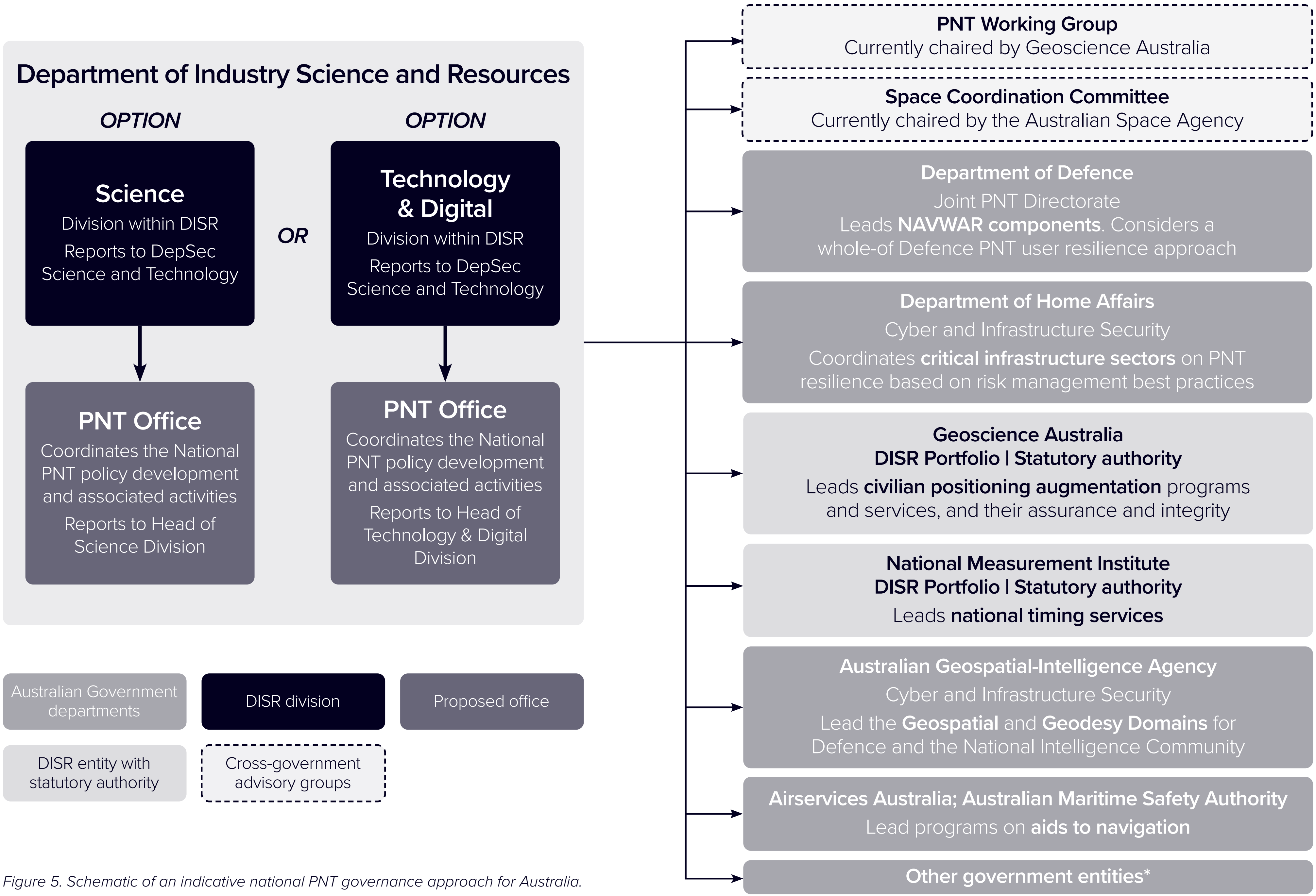

Figure 5. Schematic of an indicative national PNT governance approach for Australia.

4.2.3 Enabling PNT Governance

While a National PNT Office, as outlined above, would serve as a cornerstone for strong PNT governance in Australia, the focus should not be limited to its establishment alone. To ensure successful policy outcomes, the PNT Office should be accompanied by trusted coordination, strategic oversight, and operational accountability across the broader PNT ecosystem. The following complementary and enabling structures could be implemented, either supporting the PNT Office individually, or in tandem with the other proposed structures, by providing additional delivery and assurance functions.

4.2.3.1 National PNT Coordination Council

A National PNT Coordination Council would serve as a high-level, cross-sectoral advisory and coordination body, reporting either to a cross-portfolio ministerial committee, such as the existing whole-of-government National PNT Working Group (PNT WG), or directly to the PNT Office. Its primary role would be to provide a collaborative forum to align strategic priorities, share information, and coordinate efforts across diverse sectors.

Variations of the Coordination Council could be employed, depending on the level of authority and engagement required. An "executive" model could resemble the US National Executive Committee for Space-Based PNT, which operates under a high-level mandate with executive powers. Alternatively, a "lite" version could follow the examples of the Australian Space Industry Leaders Forum (SILF) [99], the Defence SA Advisory Board [100], or the Australia Industry Group Defence Council [101]. These are consultative bodies that comprise not just senior representatives from government, but also key ecosystem industry and research leaders to inform policy development and develop initiatives. A National PNT Coordination Council based on this model could adopt the same approach to assist and advise the National PNT Office on business, technological, and strategic aspects of PNT in Australia.

While this approach would enable collective decision-making, it may also duplicate the function of the PNT WG, be encumbered by bureaucratic processes, and its advisory nature may limit its capacity to enforce decisions or directly manage operational aspects of PNT services. It would be most effective in providing strategic oversight and fostering inter-agency collaboration, complementing operational entities responsible for implementation.

4.2.3.2 PNT Taskforce

An inter-governmental PNT Taskforce established within an appropriate government agency could provide time-bound, mission-focused outcomes in delivering a resilient national PNT solution, and could complement a PNT Office. An equivalent example may the Bushfire Earth Observation Taskforce, established by the Australian Space Agency following the devastating 2020 bushfires in Australia to conduct extensive stakeholder consultations, analyse data and decisions, and make targeted, practical recommendations to support improved bushfire risk management [102].

From a PNT perspective, if the Australian government was tasked with strengthening national resilience through uplifting diverse PNT capabilities for critical infrastructure protection, a PNT Taskforce could play a pivotal role. The Taskforce could identify and prioritise key vulnerabilities that need to be addressed at a national level to shift towards a more resilient PNT posture.

A future state PNT Task Force could be established under DHA with representation from Defence and Geoscience Australia. Its direct connection to national security and emergency management frameworks would facilitate rapid, coordinated responses to emerging PNT threats.

While the strength of a taskforce is in its agility, its temporary nature might limit long-term strategic planning and continuity. Therefore, a clear transition plan for sustained governance and capability development would be essential beyond the taskforce's mandate.

4.2.3.3 Joint Operational Capability Centre

As PNT services underpin national security and emergency response, the risk of either accidental or deliberate disruption poses significant threats to government functionality, operational continuity, and safety. Beyond warfighting platforms, Defence requires assured, resilient PNT capabilities to support mission-critical systems, including command and control, health, and logistics networks, that may be located well outside traditional operational theatres.

To address this, there is a need for a dedicated operational function that focuses on national PNT risk assessment, and well as integration, management, and real-time coordination of PNT solutions for national security and emergency response systems.

A proposed solution is the establishment of a Joint Operational Capability Centre, housed within Defence or DHA with joint representation from Defence, cyber, and emergency management government agencies. This centre would be responsible for operational readiness of critical systems that the government depends on, and the ability to respond to PNT disruptions in real-time.

At the national level, the centre would be distinct from a National PNT Office by concentrating on the tactical application of PNT technologies to ensure operational continuity rather than overarching policy development. Within Defence, it would complement the role of the Joint PNT Directorate by addressing non-NAVWAR PNT needs, specifically those required to sustain essential mission systems. An illustration of this entity within Defence PNT governance is shown in Figure 7.

4.2.3.4 PNT Accelerator

Given its vast geography and diverse environments, Australia faces unique challenges in ensuring resilient PNT compared to many other nations. Traditional GNSS solutions may be insufficient for attaining a resilient PNT posture, across both urban versus remote areas or mobile versus static applications. The lack of alternative or complementary solutions creates a vulnerability that should be addressed through domestic capability development.

To overcome this there is a need for an innovation-led approach to research, develop, and validate alternative PNT solutions tailored to Australia's specific challenges. This includes piloting diverse technologies to ensure resilience across various scenarios that are robust and scalable.

A proposed solution is a PNT accelerator or sovereign program entity, co-funded by government and industry, to drive development and adoption of next-generation or even alternative foundational PNT capabilities. Distinct from a policy-centric PNT Office, this entity would be innovation-driven, fostering public-private partnerships to accelerate the deployment of cutting-edge PNT technologies. It would need to work in tandem with strategic and operational bodies to ensure alignment with national objectives.

4.2.3.5 PNT Assurance, Integrity, Monitoring (AIM)

The alternative options described above represent those that can govern, advise on, and implement PNT at a national level. Complementing these functions is a critical need for assurance, integrity, and monitoring. The AIM function would be specifically tasked with establishing standards, accrediting systems, and verifying the operational readiness of PNT services across sectors. It could provide a form of a PNT "stamp of approval", certifying the reliability, trustworthiness and suitability of capabilities, signals, devices, for use across Defence assets, systems of national significance, and critical infrastructure.

A PNT AIM body could be modelled on existing cybersecurity assurance mechanisms. For example, the Australian Cyber Security Centre (ACSC) operates within the Australian Signals Directorate and plays a national leadership role in cybersecurity advice, incident response, and standards. While not an independent authority, the ACSC partners widely with industry and government to influence national security and infrastructure resilience. An equivalent PNT AIM body could operate within an appropriate host department such as DISR or Home Affairs.

Another possible model is an integrity and monitoring program embedded within an operational platform, such as Geoscience Australia's SouthPAN. This model could build on existing GNSS augmentation and monitoring programs, with a focus on technical integrity and signal validation for a range of sectors.

Alternatively, an independent authority could be established. For example, bodies such as CASA, AMSA, or the Australian Energy Market Operator have legislated powers to set standards, certify systems, and enforce compliance for navigation and timing respectively, though these are sector-specific. As PNT is cross-cutting and underpins a wide range of sectors, a federated model may be needed, where a national PNT assurance body sets core standards and coordinates integrity frameworks, while sector-specific regulators implement tailored assurance mechanisms within their respective domains. This approach ensures alignment with national standards while accommodating the unique operational and PNT risk profiles of each sector.

Each of these PNT ecosystem components offers unique strengths and would address different aspects of PNT governance and resilience. Depending on national priorities and resource allocations, a combination of these approaches could be implemented to create a comprehensive and robust PNT governance framework (Figure 6).

4.2.4 Defence PNT Governance

A critical consideration is that such a National PNT Office may not be a wholly appropriate vehicle for managing highly secure or classified PNT capabilities, such as Defence-protected signals or military-grade devices operating within secure domains. While Defence would be a key stakeholder and contributor to the National PNT Office, it would also require its own internal governance arrangements to manage Defence-specific requirements, risks, and operational mandates.

There are several Defence divisions, agencies, and entities engaged in PNT initiatives. However, it is unclear whether a dedicated PNT governance framework exists or how these various programs are integrated. One proposed model is a structure similar to the US DOD tri-chair model for DOD PNT, adapted for the Australian context. Here, the different Australian Defence entities would contribute in specialised roles to support a resilient and assured military PNT posture.

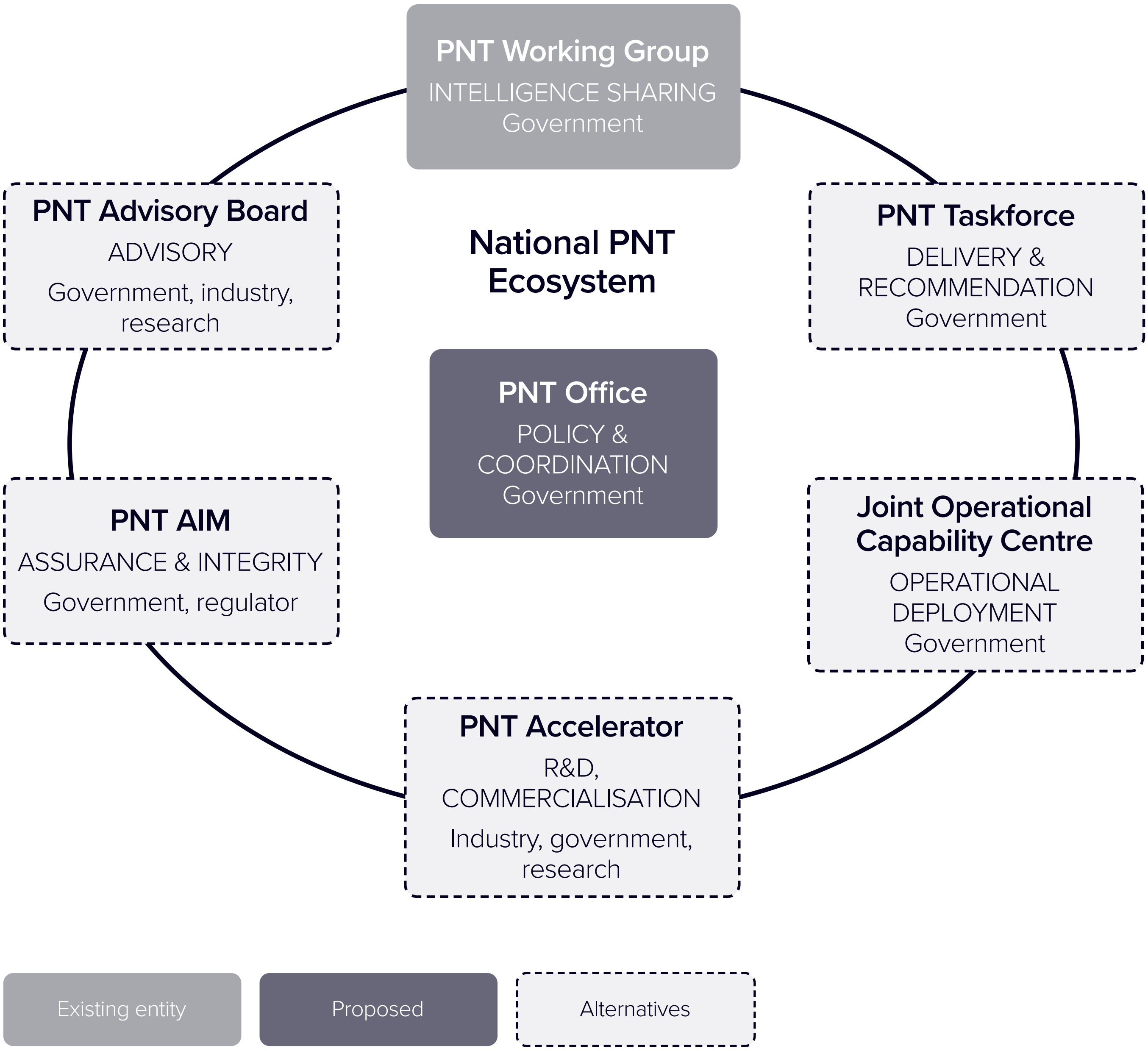

Figure 6. An ecosystem perspective of a resilient PNT governance framework, with one or more enabling structures that could complement a PNT Office and the PNT Working Group.

The schematic in Figure 7 illustrates a plausible structure, where a Defence PNT Executive Committee or Council oversees Defence PNT activities, while maintaining a formal relationship with the National PNT Office to represent Defence interests and ensure alignment. The Defence PNT Executive Committee would also provide oversight and strategic direction to the following core functions:

- Defence Science and Technology Group – R&D in assured PNT;
- Advanced Capabilities Strategic Accelerator – rapid translation of PNT technologies into minimum capable viability;
- Joint PNT Directorate – front-door coordination of NAVWAR architectures, capabilities, test and evaluation, and deployment onto warfighting assets;
- Space Operations – monitoring and intelligence analysis of space-based PNT;
- Joint Capabilities Division, Australian Signals Directorate – counter-PNT activities;
- Joint Operational Capability Centre – operational deployment of PNT capabilities (non-NAVWAR) for national security and emergency management.

In this schematic, the Joint Operational Capability Centre (proposed function referenced in Section 4.2.3.3) has dual accountability, reporting to both the Defence PNT Executive Committee and the National PNT Office. Its role would be distinct from that of the Joint PNT Directorate, with a mandate focused on ensuring overall user resilience for Defence. This would include addressing vulnerabilities and mitigating risks to PNT dependencies within Defence's supporting infrastructure and mission systems (discussed further in Section 4.3.3 on User Resilience).

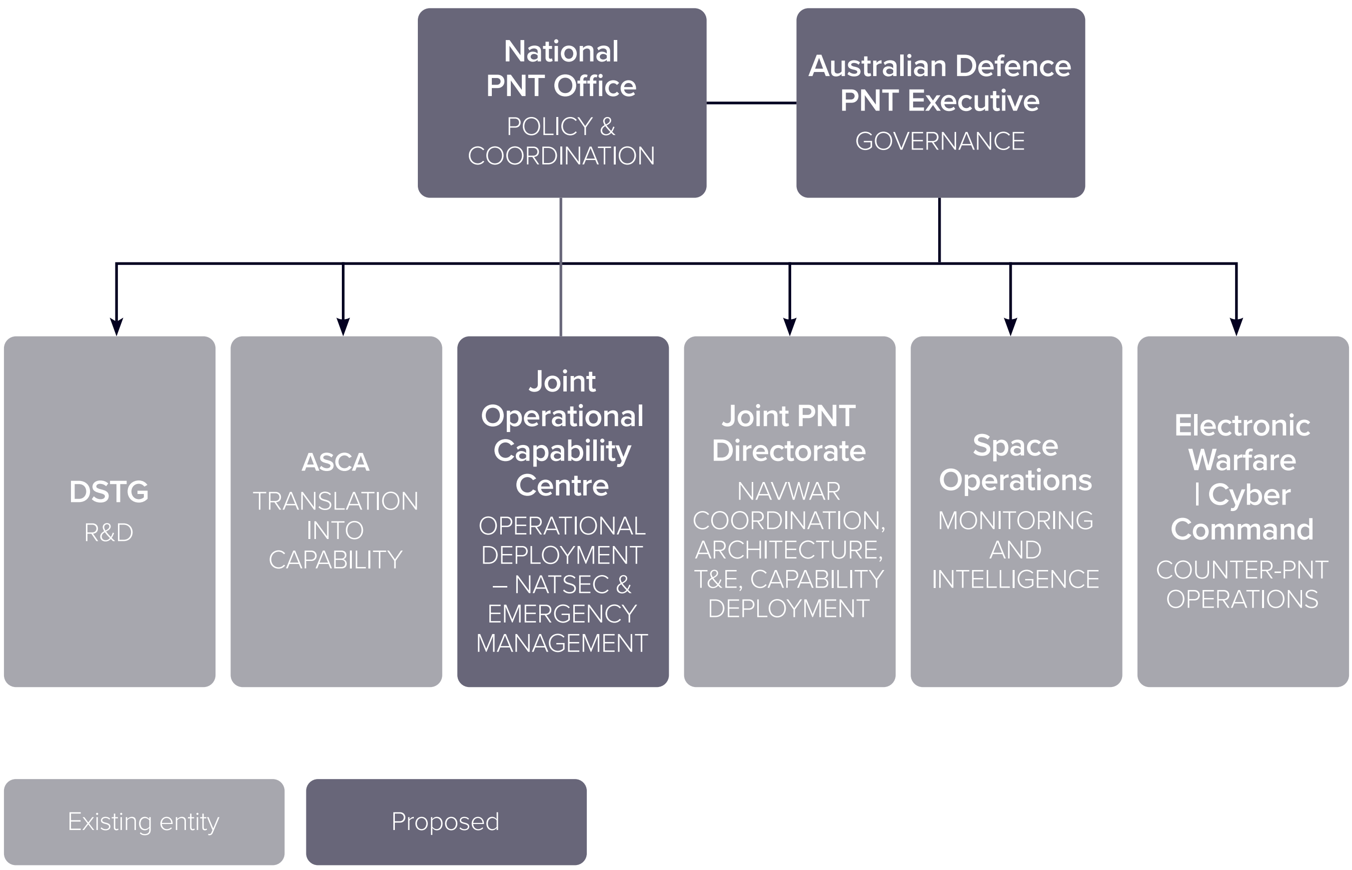

Figure 7. A schematic of a Defence PNT governance framework.

4.3 Technological diversity

4.3.1 Innovation is only part of PNT resilience

4.3.1.1 Quantum

Defence is exploring the integration of quantum technologies for PNT, such as through the procurement of quantum optical clocks [103], development of advanced inertial systems, and ground-to-satellite optical quantum links to enable a quantum-secured timing network [104]. Additionally, Defence's investment in quantum capabilities for NAVWAR (via R&D initiatives funded by the ASCA and DSTG Office [105]) aligns with AUKUS Pillar II priorities and the AUKUS Quantum Arrangement, and signals a strategic focus on future-state technologies for assured PNT.

This approach however comes with capability and operational risks. Quantum technologies are generally yet to achieve commercial or operational-scale validation, and it is little understood what quantum, integrated into PNT, truly means. While the long-term vision is to deliver assured PNT for the warfighter, this focus on unproven next-generation solutions risks overlooking a more immediate vulnerability. Defence continues to be reliant on civilian PNT infrastructure, including public GNSS and critical energy and telecommunications networks, which remain largely outside Defence control.

There is also a limitation in Defence's current posture, that being a "buy vs build" tension, especially in relation to platform procurement from key allies such as the US. Australia's acquisition of integrated systems often restricts local modification in the interest of interoperability, which may result in capability mismatches when considering quantum integration.

To mitigate such risks, an approach is needed that balances investment in emerging technologies with near-term enhancements to foundational, proven capabilities. These may include hardened GNSS receivers (military and civilian), alternative timing sources (space-based and/or terrestrial), and integration of military and civil PNT resilience planning. Building sovereign capability will also require sustained investment in Australia's own technology ecosystem. This includes support for companies developing quantum clocks, inertial navigation systems, robust receivers, and multi-sensor fusion platforms. These technologies are critical for enabling PNT services that are resilient in GNSS-denied environments, and they represent areas where Australia can build comparative advantage. Targeted R&D funding, procurement policies, and dedicated PNT test ranges will be essential to accelerate this development.

Australia has the opportunity to strengthen its national PNT resilience by developing a diversified ecosystem that draws on multiple signal sources, both space-based and ground-based. A robust national PNT strategy would integrate multiple signal types to form overlapping, redundant layers, minimising single points of failure and improving continuity under disruption. While detailed considerations of alternative PNT systems are not within the scope of this paper, it is worth highlighting some observations.

4.3.1.2 Terrestrial Broadcast

Development of sovereign terrestrial systems, much like the eLORAN network proposed by the UK, could provide a layer of deterrence, complementing hardened and encrypted satellite-based solutions. Whilst eLORAN is a prevalent technology, it is not the only option for terrestrial PNT broadcast. MF R-mode, mentioned in Section 3.4.3, and LocataTech, a privately patented radio-location positioning and timing technology based on a network of ground-based time-synchronised transceivers (or pseudolites), are just some of the other alternative options. MF R-mode is currently being trialled by Canada.

Several terrestrial PNT systems have been tested in the alternative PNT assessment carried out by DEFIS in Europe in 2023 [106]. Further work however is needed to evaluate the infrastructure requirements, cost-benefit trade-offs, and operational models of the various terrestrial broadcast systems.

4.3.1.3 Space

Alternatives to GNSS do not need to be exclusively terrestrial-based. Given Australia's vast landmass and dispersed population, space-based systems may offer better scalability and wide-area coverage. While space solutions are capital intensive, there may be opportunities to take advantage of economies of scale, such as through multi-GNSS capabilities and/or LEO PNT.

Australia is well-positioned in the southern hemisphere to benefit from multiple GNSS constellations. For example, Galileo signals are already utilised by SouthPAN. The Japanese QZSS also presents a strategic opportunity for Australia and the broader Indo-Pacific region. Expanding formal engagement with additional GNSS providers could enhance resilience and foster regional partnerships.

LEO PNT systems are an emerging frontier for space-based navigation and timing. Unlike traditional GNSS which has been largely government-funded, the LEO PNT ecosystem is being driven primarily by private sector investment [43].

For Australia and for Defence, one possible pathway for securing LEO PNT capabilities could lie in the repurposing of the JP9102 program, originally conceived as a sovereign geostationary SATCOM capability [107] to reduce reliance on other countries' satellites. In response to the evolving threat landscape, including the increasing vulnerability of geostationary systems to hostile actions, Defence is re-evaluating the architecture of JP9102 to support a more distributed and resilient model [108]. Should JP9102 evolve into an agile LEO constellation, it may present a cost-effective opportunity to host co-located PNT payloads, avoiding the need to invest in a standalone LEO PNT system. This dual-purpose approach could deliver greater value from existing investments while contributing to PNT resilience.

Another option would be to leverage a commercial LEO constellation for dual-use purposes, including the provision of PNT services, like in the US.

4.3.2 International collaboration

International cooperation should also be deepened. Japan, with its mature QZSS program and strong space sector, is a natural regional partner. But emerging spacefaring nations such as India and South Korea are also developing PNT capabilities and share interests in Indo-Pacific stability and technological development. Australia's PNT strategy should actively cultivate ties with these countries, both for joint research and to strengthen regional system interoperability.

Another critical opportunity lies in the commercial domain. The United States is leading the way in fostering private sector-led LEO PNT solutions. Australia should examine similar models. By partnering with or supporting commercial ventures to deliver LEO-based PNT services, Australia can leverage market innovation while retaining policy influence and operational access.

Building sovereign capability will also require sustained investment in Australia's own technology ecosystem. This includes support for companies developing quantum clocks, inertial navigation systems, robust receivers, and multi-sensor fusion platforms. These technologies are critical for enabling PNT services that are resilient in GNSS-denied environments, and they represent areas where Australia can build comparative advantage. Targeted R&D funding, procurement policies, and dedicated PNT test ranges will be essential to accelerate this development.

4.3.3 User resilience is key

The current approach of various government agencies pursuing different PNT technologies, but without a national framework to guide user adoption, will not deliver try PNT resilience. Resilience is not simply about acquiring or deploying technologies, it depends on coordinated governance, widespread user adoption, and long-term planning. For instance, in the UK, the development of SBAS and eLORAN is explicitly complemented by receiver development and integration pathways outlined in the UK Resilient PNT Framework.

Government plays a critical role in enabling PNT resilience at the user level, not just ensuring the robustness of infrastructure, but the continuity of services across all sectors that rely on it, including defence. This user-centric dimension is currently underdeveloped in Australia's approach. While Geoscience Australia and Land Information New Zealand successfully secured an SBAS capability through SouthPAN, there are no coordinated plans to support the development of compatible receivers that can drive broader user adoption. SouthPAN has been broadcasting live signals since September 2022, however two of its three services, namely Dual Frequency Multi Constellation (DFMC) SBAS and Precise Point Positioning (PPP) are currently not supported by the receiver manufacturers, meaning that the benefits of SouthPAN are not being realised to full potential.

Investments in infrastructure are important, but so too is ensuring that receivers, systems, and applications across the economy are designed to detect anomalies, switch to backups, and maintain functionality under degraded conditions. The United States' emphasis on resilient user equipment is a useful benchmark.

For Defence, the nuance might be in shifting the focus from platform-level assurance to include user-level resilience. Rather than pursuing efforts to achieve assured PNT for the warfighter only, the scope should extent to enabling resilient PNT for critical support functions. These might range from energy supply to the Defence networks that underpin logistics, health, and command and control in day-to-day operations (refer to Figure 7 for a proposed Defence capability). In this way, PNT resilience becomes not just a tactical advantage, but a foundation for operational continuity and sustainment.

4.4 Civil-military coordination in PNT infrastructure

There is limited public information on the extent of Defence's reliance on civilian PNT infrastructure. However, it is likely that civilian systems are used in certain circumstances in both the air and maritime domains. In the civilian sector, aviation will utilise SouthPAN for safety-of-life and navigation services, once it becomes certified, which at the moment is targeted for 2028.

Defence aviation does not fall under the jurisdiction of the CASA rules directly, as it operates under a separate regulatory framework, the Defence Aviation Safety Regulations [109]. However, Defence does work cooperatively with CASA in areas where military and civilian aviation interact, such as shared airspace and air traffic control in joint-use airports, for example Townsville Airport (RAAF Base Townsville) [110].

In the maritime domain, a 2023 Memorandum of Understanding between Defence and AMSA outlines processes for transferring vessels from civilian to Defence flag administration [111]. This arrangement supports naval capability and safety-at-sea support, and implies that such vessels, when under Defence flag, may rely on civilian PNT infrastructure such as SouthPAN for PNT services.

While SouthPAN is a government-owned asset and service, there are instances where the military has engaged with or tested commercial PNT capabilities. These include inertial navigation systems developed for civilian applications such as subsea exploration [112], space launch support [113], as well adaptations for Defence land-based combat systems [114]. Other technologies involve Australian-developed ground-based positioning networks capable of creating localised positioning signals that can operate in environments where GNSS is denied or degraded. Such systems have been deployed in mining operations in Australia [115], but also tested internationally by the US Air Force [116], indicating their potential suitability for both commercial and strategic cases. To date however, there is no publicly available information on adoption by the Australian Defence Force.

4.5 Flavours of sovereignty

4.5.1 Ownership vs stewardship

One of the key takeaways from international stakeholder engagements is that the Australian government does not need to own all PNT infrastructure outright, whether civil or military. Instead, global PNT ecosystem experts have suggested the Australian government's primary role should be in policy leadership, standard setting, and strategic coordination, including leading the development of a national PNT framework that ensures widespread, secure, and resilient access across civil and defence domains. This would enable the adoption or scaling of locally-developed innovations, with the overarching goal of ensuring resilient PNT access for users across the civilian and defence sectors.

This model would also enable greater participation from Australian industry, research institutions, and state agencies in delivering PNT capability. By clearly articulating national performance requirements, interoperability standards, and assurance expectations, the Government could create the conditions for public-private partnerships, without assuming sole responsibility for infrastructure ownership or operation.

A relevant precedent can be found in the civilian space industry. Saber Astronautics was contracted to develop, and now operates, Australia's national space mission control centre [117], co-located physically with the Australian Space Agency in Adelaide. For PNT, threat intelligence and monitoring may offer a near-term opportunity to trial public-private partnerships models, potentially leveraging or extending on space and cyber threat analysis and intelligence centres that already exist in Australia. Examples of two-way sharing platforms in space and cyber include the Australian Signals Directorate's Cyberthreat Intelligence Sharing platform; the Critical Infrastructure Information Sharing and Analysis Centre (CI-ISAC); the Space-ISAC; and a range of commercial offerings.

Over time, public-private partnerships approaches could be extended to support more capital-intensive PNT infrastructure programs. This could provide a pathway for deterrence through sovereign capability delivery, while leveraging private sector expertise and innovation.

4.5.2 PNT as a utility

While some capabilities, such as threat modelling and identification, can be reasonably led by industry, others will require direct government leadership and stewardship. For example, development of national timing backup capabilities, critical for maintaining synchronisation across energy, telecommunications, financial services, and defence systems, is unlikely to emerge without government direction and investment.

For Australia, a more integrated, whole-of-government model could offer improved efficiency and resilience. A national timing backup system would not replace the need for Defence-specific capabilities to ensure global operational reach. However, it would recognise that precise timing is a foundational service that underpins critical infrastructure across both civil and military domains. Like these essential services, national timing would require assurance, traceability, continuous monitoring, and good governance.

Framing PNT as a utility would also enable clearer national messaging. It shifts the conversation away from narrow technological or "space sector" vulnerabilities or investments, towards protecting economic continuity and national security. This framing opens the door to coordinated cross-sector and cross-government planning, and supports stronger public support for investment in infrastructure for PNT as the *invisible utility*.

5 CONCLUSION

This report has examined how five technologically advanced nations – the United Kingdom, United States, European Union, Canada, and Japan are building PNT resilience, offering valuable insights for Australia.

A central insight from this analysis is that resilient PNT requires a system-of-systems architecture. No single solution, whether satellite-based, terrestrial, or inertial, is sufficient on its own. Instead, robust national strategies integrate multiple technologies and governance layers to continuity, redundancy, and sovereignty.

Australia, which is unlikely to pursue its own GNSS constellation, can draw from the UK and Canada models, that is, to achieve PNT sovereignty through a deliberate coordinated governance, capability development, layered service integration and cooperation with like-minded allies. Currently, Australia's PNT initiatives are fragmented, with no single entity responsible for oversight or coordination. This leaves the nation vulnerable to emerging threats and dependent on ad hoc responses. A National PNT Office with cross-government authority would be a critical first step to unify efforts, set strategic direction, and manage national PNT risk.

Timing resilience is another urgent priority. National reliance on GNSS-derived timing leaves critical infrastructure vulnerable to disruption. Diversifying timing sources, drawing from Japan's NICT and the UK's NTC frameworks, could be pursued, with adaptation to Australia's unique geography.

On the positioning front, while initiatives like SouthPAN are promising, Australia needs to do more to mitigate the risks of GNSS-dependence. Consideration of terrestrial and alternative technologies, especially in urban, strategic, and contested domains, is essential to complement space-based PNT.

Australia has both the opportunity and the responsibility to act. PNT resilience is not a technical upgrade, it should be a national security and defence priority. Australia needs policy leadership, strong governance and coordinated investment to implement and scale PNT capability, and to secure its position as a trusted and capable PNT nation in the Indo-Pacific.

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We know where.