Beyond GPS: Quantum PNT in Great-Power Competition

Rebalancing Deterrence and Alliance Architecture in the Indo-Pacific

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Contents

1 Introduction

The operational premise that U.S. weapon systems will reach their intended targets increasingly depends on contested enabling functions rather than on platform performance alone.[1] This assumption has deep historical roots. In the interwar period, airpower advocates, later associated with what became known as the *Bomber Mafia*, argued that technological advances in speed, altitude, and payload made air defense ineffective. This belief was famously captured by British Prime Minister Stanley Baldwin's assertion that "the bomber will always get through".[2]

History proved this assumption incorrect. Adversaries adapted through radar, integrated air defense systems, and fighter interception. By doing so, they undermined the assumption that bomber penetration was inevitable. The episode illustrates a recurring pattern in military affairs: confidence in enabling technology often precedes an adaptive response that undermines its presumed reliability.

Among contemporary enabling functions, Global Positioning System (GPS)-derived Positioning, Navigation, and Timing (PNT) plays a role as central as that once attributed to the bomber. Precision strike, joint command-and-control, synchronized fires, and coalition interoperability all depend on assured PNT. As with earlier technological assumptions, reliance on GPS is increasingly challenged by an adversary's ability to contest it.

In the Indo-Pacific, the People's Republic of China (PRC) possesses both the capability

1. Artificial intelligence tools (ChatGPT, LeChat, and Grammarly) were used in the creation of this paper for spelling and grammar checks, refinement of sentence structure, and structured red-teaming of arguments. All content, analysis, interpretations, and conclusions reflect the author's original ideas, were reviewed and verified by the author, and are presented in accordance with applicable academic integrity standards. Additionally, I would like to thank Lt. Col. Brandon Vigneron for his excellent comments and recommendations from his peer review.

2. Stanley Baldwin, "Speech to the House of Commons: The Bomber Will Always Get Through," House of Commons Debate, Hansard, Vol. 270, cc. 632–643, November 1932, https://hansard.parliament.uk/commons/1932-11-10/debates/3a0265a1-9983-40e7-9abd-50e0c759cea6.

and the geographic advantage to degrade or deny GPS regionally through jamming and spoofing. Because the United States and many regional partners remain highly dependent on space-based PNT, while China benefits from a more resilient, partially terrestrial PNT ecosystem, the resulting asymmetry creates not only tactical risk but also strategic vulnerability. If PNT denial undermines U.S. and allied operational effectiveness, it erodes the credibility that underpins extended deterrence.

U.S. responses to PNT vulnerability have largely emphasized incremental hardening of space-based architectures and the protection of advanced enabling technologies through restrictive release policies. This approach risks reproducing the same logic that underpinned earlier technological overconfidence: dependence that is not matched by sufficient resilience. At the coalition level, this combination can improve U.S. survivability marginally while leaving partners exposed, enabling selective denial and political pressure against less resilient allies.

RAND's assessment of emerging technologies in deterrence identifies quantum sensing as a potentially significant contributor to future deterrence relationships, while cautioning that quantum inertial navigation systems may not reach sufficiently favorable Size, Weight, Power, and Cost characteristics in the near term.[3] At the same time, the same report highlights that multilateral development of sensing technologies could generate meaningful deterrent value for partners and allies.[4] This tension creates a question: how should the United States prepare to employ quantum-enabled PNT to strengthen deterrence in the Indo-Pacific without replicating earlier patterns of technological overconfidence or creating new alliance vulnerabilities?

As summarized in Figure 1, quantum sensing technologies fall into a category where

3. Michael J. Mazarr et al., *Disrupting Deterrence: Examining the Influence of Emerging Technologies on Strategic Stability and Deterrence*, PEA2263-1 (Santa Monica, CA: RAND Corporation, 2022), 34, https://doi.org/10.7249/PEA2263-1, https://www.rand.org/pubs/perspectives/PEA2263-1.html.

4. Mazarr et al., 64.

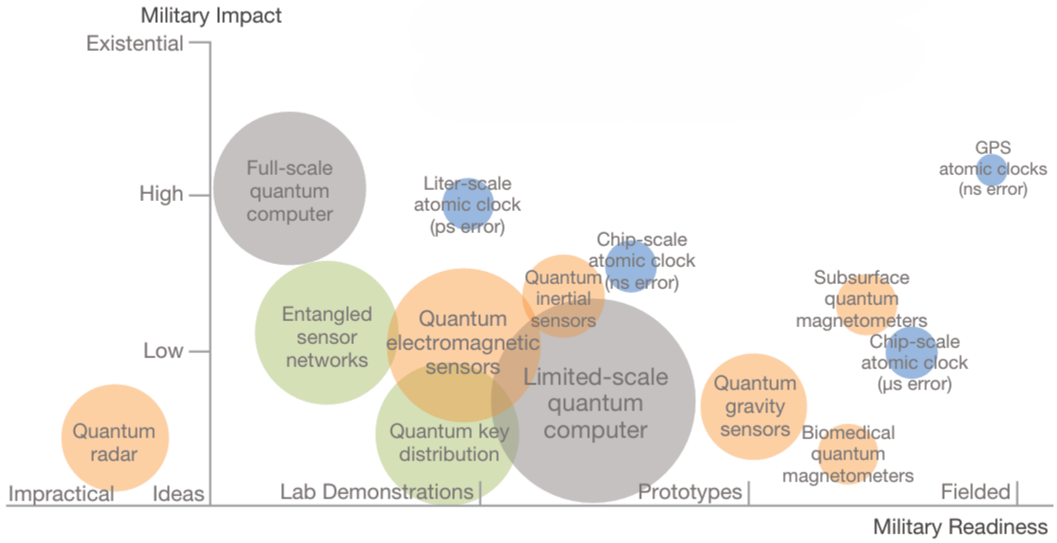

Figure 1: Overview of selected quantum technologies by military readiness and military impact

military impact may be substantial even as readiness and fielding timelines vary. The figure is not predictive, but it illustrates why quantum-enabled navigation deserves early conceptual and policy analysis before mature deployment.

This paper focuses on quantum-enabled PNT as a resilience-enhancing capability in GPS-denied environments, with primary attention to conventional joint operations in the Indo-Pacific. It does not attempt to forecast precise technology timelines, design a comprehensive acquisition program, or assess all quantum domains. Instead, it treats quantum-PNT as a useful case for examining and improving coalition resilience under PNT denial. The competitive context is important, as China invests heavily in quantum technologies, and relative advantages differ across quantum domains.[5]

This paper argues that sustaining extended deterrence in the Indo-Pacific requires shifting

5. U.S. Department of Defense, *Fiscal Year 2020 Industrial Capabilities Report to Congress* (Washington, DC: U.S. Department of Defense, January 2021), 93, https://www.businessdefense.gov/Portals/51/Documents/Resources/2021%20Industrial%20Capabilities%20Report%20to%20Congress.pdf; Edward Parker, Daniel Gonzales, Ajoy K. Kochhar, et al., *Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology*, RR-A869-1 (Santa Monica, CA: RAND Corporation, 2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.

U.S. PNT strategy from space-centric dependence and technology hoarding toward coalition-focused resilience. Specifically, controlled sharing of quantum-enabled PNT with selected Indo-Pacific allies can strengthen deterrence by denial and deterrence by punishment by preserving coalition operational effectiveness under GPS denial, while simultaneously reinforcing alliance credibility through visible, long-term commitment.

Chapter 2 establishes the deterrence framework and links credibility to coalition performance, critical enabling functions that can be contested. Chapter 3 applies this framework to Indo-Pacific alliance dynamics and explains why GPS denial generates asymmetric risks for U.S. and partner forces. Chapter 4 examines quantum-PNT as a resilience layer within a hybrid PNT architecture and outlines its principal technical approaches and constraints. Chapter 5 analyzes controlled technology sharing as an alliance instrument and assesses how quantum-PNT sharing affects deterrence by denial, punishment, and political commitment. Chapter 6 evaluates quantum-PNT as a case study of coalition resilience, including tradeoffs and likely PRC responses. Finally, Chapter 7 offers policy recommendations for early integration with a focus on the Indo-Pacific and controlled sharing to strengthen deterrence while managing risk.

2 Deterrence

Deterrence constitutes a foundational element of U.S. foreign and security policy and is therefore reflected across major national security and defense strategy documents. As stated in the 2025 National Security Strategy (NSS), economic measures directed at China must be complemented by “a robust and ongoing focus on deterrence”.[6] By contrast, the 2022 NSS places greater emphasis on deterrence through the maintenance of a credible combat military, explicitly situated in relation to allies and partners.[7] The 2025 National Defense Strategy (NDS), in line with the 2025 NSS, placed greater emphasis on increasing power in the Western Hemisphere than on deterring China in the Indo-Pacific with military means.[8] Relative to the 2022 NSS, the 2025 NSS places less explicit emphasis on deterrence as a discrete concept. Instead, deterrence is framed more implicitly through notions such as “peace through strength” and through the coordinated application of non-military instruments of power, particularly economic statecraft. This shift reflects a change in emphasis rather than a departure from the underlying logic of deterrence. Although the updated National Military Strategy (NMS) has not yet been released, its content is expected to align with the strategic priorities articulated in the 2025 NSS. Deterrence remains inherently multifaceted, encompassing multiple government departments, joint force integration, and operations across all domains of warfare. Consequently, developments that affect performance in any operational domain can influence deterrence outcomes. Virtually all tactical,

6. The White House, *National Security Strategy of the United States of America*, National Security Strategy, Executive Office of the President, Washington, DC, October 2025, 20, https://www.whitehouse.gov.

7. The White House, *2022 National Security Strategy of the United States of America* (Washington, D.C.: The White House, October 2022), 24, https://www.whitehouse.gov/wp-content/uploads/2022/10/Biden-Harris-Administrations-National-Security-Strategy-10.2022.pdf.

8. U.S. Department of Defense, *National Defense Strategy*, Unclassified Summary, U.S. Department of Defense, January 2026, accessed February 25, 2026, https://media.defense.gov/2025/May/02/2003703230/-1/-1/1/MEMORANDUM-DIRECTING-THE-DEVELOPMENT-OF-THE-2025-NATIONAL-DEFENSE-STRATEGY.PDF.

operational, and strategic military capabilities rely heavily on GPS-derived Positioning, Navigation, and Timing (PNT), making it a critical enabling function across the joint force. Because deterrence is closely tied to overall defense effectiveness, degradation of foundational enablers such as PNT directly affects the credibility of U.S. deterrent threats and, by extension, the effectiveness of the U.S. national defense strategy. This connection underscores why technical vulnerabilities can translate into strategic consequences. To understand how such vulnerabilities translate into deterrence outcomes, it is necessary to examine how deterrence is conceptualized within U.S. defense strategy.

The 2026 National Defense Strategy situates deterrence within an integrated and politically grounded framework. According to the 2026 NDS, deterrence by denial is the preferred framework. This is a change from the 2022 NDS, which used integrated deterrence. The 2022 NDS defined integrated deterrence as "using every tool at the Department's disposal, in close collaboration with other departments and agencies, and in concert with our allies and partners, to deter aggression in multiple domains of warfare and across the spectrum of conflict".[9] Political scientist Michael J. Mazarr similarly argues that "deterrence is a political, not a technical, challenge".[10] Both NDS versions convey the same idea, but use different terms to express it. Deterrence is therefore not determined by the mere possession of advanced military capabilities, but by how those capabilities shape an adversary's perception of intent, resolve, cohesion, and anticipated costs. Integrated deterrence embeds this political logic by explicitly linking military means to diplomatic alignment, economic coordination, and allied cooperation.

9. U.S. Department of Defense, *2022 National Defense Strategy of the United States of America* (Washington, DC: U.S. Department of Defense, October 2022), 4, https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF.

10. Mazarr et al., *Disrupting Deterrence: Examining the Influence of Emerging Technologies on Strategic Stability and Deterrence*, 62.

Technology influences deterrence only indirectly, by affecting credibility. What ultimately matters is the perceived willingness and ability of the United States and its allies to act collectively, rapidly, and at acceptable cost. It is this cost–benefit calculation that the People's Republic of China (PRC) continuously evaluates when considering whether and when to act decisively with respect to Taiwan. Any such action would likely be cross-domain in character and involve a combination of kinetic and non-kinetic means. Because deterrence is directed toward specific political objectives, its effectiveness cannot be assessed in this.

The effectiveness of deterrence varies depending on the specific action and political objective being deterred. China pursues multiple national priorities, of which reunification with Taiwan constitutes a core strategic objective.[11] Changes in deterrence effectiveness must therefore be evaluated in relation to the specific objective they are intended to influence. This requires analyzing deterrence through the lens of Chinese priorities, perceptions, and strategic culture, rather than exclusively through U.S. interests or assumptions. Chinese perspectives are often insufficiently incorporated into U.S. strategic discourse, particularly in public debate. This omission can lead to inflated stakes, where U.S. interests are overstated, or deflated stakes, where they are understated. In either case, this gap between perception and reality undermines sound deterrence analysis. Because deterrence is relational rather than unilateral, allied actors play a central role in shaping these perceptions.

Deterrence is not only a national military attribute, but a function of the perceived collective capability and willingness of allied actors. Both deterrence by punishment and deterrence by denial rely on credibility rather than absolute power.[12] The credibility of alliances

11. David C. Kang, "What Does China Want?," China's core national interests include state sovereignty, national security, territorial integrity, and national reunification, *International Security* 50, no. 1 (2025): 46–80.

12. Thomas C. Schelling, *Arms and Influence*, Deterrence works by persuading potential aggressors that retaliation will impose costs greater than benefits (Yale University Press, 1980), 69.

depends in part on their cohesion and the speed of collective decision-making.[13] Allies can therefore exert either a positive or negative influence on deterrence. Alliances strengthen deterrence by reducing an adversary's certainty in achieving quick, limited, or deniable gains. If an alliance appears resilient, interoperable, and politically cohesive, deterrence by denial becomes more credible. Conversely, visible divisions or delayed decision-making weaken deterrence by creating opportunities for opportunistic behavior. From the perspective of a potential aggressor, deterrence is assessed as a whole. The effectiveness of deterrence in an alliance context is therefore the result of a collective evaluation of coalition resolve, capability, and responsiveness. Technology plays a key role in developing these alliance perceptions by influencing expectations of operational performance under stress.

Technology influences deterrence by shaping political decision-making. By altering expected costs, risks, and the perceived likelihood of success, technology affects the cost–benefit calculations which support decisions to act. Because deterrence is fundamentally political, technology does not provide deterrence by itself, but through its effect on perception. Capabilities that increase uncertainty, reduce confidence in rapid success, or raise the anticipated costs of failure decrease the attractiveness of aggressive action. Deterrence holds when technology credibly shifts the political cost–benefit balance against escalation.

13. Iain D. Henry, *Reliability and Alliance Interdependence: The United States and its Allies in Asia, 1949–1969* (Cornell University Press, 2022), 13.

3 Deterrence and allies in the Indo-Pacific

Building on the theoretical foundations of deterrence, credibility, and perception established in the previous section, this chapter applies those concepts to the Indo-Pacific theater. Alliance dynamics, geography, and force posture decisively shape deterrence outcomes.

This theater-specific analysis follows Mazarr's argument that the deterrence effects of emerging technologies and military capabilities are inherently political and vary according to the strategic objective, the adversary's perceptions, and the operational context in which they are applied.[14]

U.S. allies and partners in the Indo-Pacific influence deterrence with respect to China in ways that are complex and, in some cases, counterintuitive. As Mastro argues, deterrence in the Indo-Pacific is complicated by both the character of Chinese coercive strategies and the regional distribution of U.S. and allied military power.[15] China possesses a wide range of non-kinetic options that can be employed across both the competition and conflict phases.[16] Unlike traditional deterrence models that rely primarily on overt military threats, Chinese strategy increasingly emphasizes non-kinetic and cross-domain instruments, including cyber operations, economic coercion, and political influence. These tools complicate attribution, escalation management, and proportional retaliation. As a result, the presence of U.S. allies in the region does not automatically strengthen deterrence by punishment, particularly when allied governments face unequal political and economic exposure to Chinese retaliation. In this context, allied participation may introduce hesitation, constraints, or varying levels of political risk tolerance,

14. Mazarr et al., *Disrupting Deterrence: Examining the Influence of Emerging Technologies on Strategic Stability and Deterrence*, 52–54.
15. Oriana Skylar Mastro, "Deterrence in the Indo-Pacific," *Asia Policy* 17, no. 4 (2022): 10.
16. Mastro, 13.

thereby weakening deterrent signaling rather than reinforcing it. Deterrence by punishment in the Indo-Pacific, therefore, depends not only on military capability but on allied political willingness to absorb costs and sustain escalation. These challenges are compounded by structural constraints on deterrence by denial that are specific to the Indo-Pacific theater.

Deterrence by denial in the Indo-Pacific is constrained by geography and regional force posture. The United States maintains a limited force posture in close proximity to the Taiwan Strait, while China benefits from geographic proximity and a dense regional basing network.[17] According to open-source assessments cited by Mastro, the United States operates only two air bases within approximately 1,000 miles of the Taiwan Strait, whereas China operates approximately 39 air bases within 500 miles of Taipei.[18] This asymmetry constrains the U.S. ability to rapidly project and sustain combat power during the early phases of a conflict. Allies can partially mitigate these limitations by providing access, basing, and logistical support. However, even when allied contributions are limited to enabling or sustainment roles, such support exposes allied states to Chinese diplomatic, economic, and political retaliation. While the precise number of operationally relevant bases depends on classification criteria, the disparity in proximity and basing density is sufficient to generate a clear and significant asymmetry in power projection and sustainment in the early stages of a conflict. Deterrence by denial in the Indo-Pacific, therefore, depends not only on military access and posture but also on the willingness of allies to accept political and economic risk. This willingness cannot be assumed and varies across partners, domestic political contexts, and specific contingencies. These structural limits on deterrence by denial require approaches that reduce reliance on expanded

17. Mastro, "Deterrence in the Indo-Pacific," 15.
18. Mastro, 10.

force posture or increased allied exposure.

Enhancing resilience against GPS denial strengthens deterrence by denial while limiting additional political burdens on allies. Chinese military strategy seeks to degrade U.S. operational effectiveness by targeting critical enabling capabilities, including GPS-derived PNT. Mitigating GPS degradation alters the operational balance by reducing the effectiveness of Chinese counter Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, and Reconnaissance (C5ISR) efforts and disrupting of Joint All-Domain Command and Control (JADC2). Improved PNT resilience reduces China's confidence in its ability to achieve rapid denial effects through non-kinetic means. By preserving navigation, timing, and coordination under contested electromagnetic conditions, resilient PNT complicates Chinese operational planning and increases uncertainty regarding feasibility, timing, and costs. Consistent with Mazarr's assessment that emerging technologies influence deterrence by shaping expectations of success rather than providing deterrence in isolation, improved PNT resilience primarily affects Chinese perceptions of whether early escalation strategies can achieve decisive effects.[19] By reducing dependence on vulnerable space-based signals without requiring a visible expansion of force posture, PNT resilience reinforces deterrence by denial while minimizing allied political exposure. Beyond deterrence by denial, resilience against GPS disruption also affects deterrence by punishment.

Mitigating GPS denial contributes to deterrence by punishment by preserving credible U.S. and allied strike capabilities. Deterrence by punishment depends on the perceived ability to hold adversary forces and critical infrastructure at risk, even under degraded conditions.[20]

19. Mazarr et al., *Disrupting Deterrence: Examining the Influence of Emerging Technologies on Strategic Stability and Deterrence*, 52–54.
20. Schelling, *Arms and Influence*, 69.

Reliable PNT underpins the effectiveness of both kinetic and non-kinetic targeting chains across domains.[21] If Chinese leaders assess that U.S. and allied forces can reliably generate military and non-military effects despite GPS denial, the expected costs of aggression increase. This logic applies across domains, including cyber and other non-kinetic arenas, where the credibility of retaliation shapes adversary decision-making. Preserved PNT functionality, therefore, sustains the credibility of punishment-based deterrent threats. By increasing the likelihood that U.S. and allied forces can impose costs under contested conditions, PNT resilience strengthens deterrence by punishment without requiring overt escalation or additional forward deployment. These deterrence dynamics must be understood within the broader context of China's long-term military development and strategic intent.

China's emphasis on GPS denial reflects a deliberate effort to counter U.S. military advantages developed since the end of the Cold War. Following extensive analysis of the 1991 Gulf War, China revised its military strategic guidelines and invested heavily in countering U.S. advantages in precision strike, C5ISR, and satellite-enabled warfare.[22] Many of the capabilities that most impressed Chinese analysts during the Gulf War depend critically on reliable PNT. Over time, China developed both indigenous alternatives and denial capabilities designed to exploit U.S. dependence on GPS. These efforts disproportionately affect U.S. expeditionary forces, while China benefits from a regionally optimized PNT architecture and extensive terrestrial backup systems.[23] Chinese GPS denial imposes higher relative costs on U.S. expeditionary forces than on

21. Joseph S. Jr. Nye, "Deterrence and Dissuasion in Cyberspace," Discusses threat of punishment and other mechanisms in cyber deterrence, *International Security* 41, no. 3 (2016): 44–71.
22. Kristen A. Gunness et al., *China's Incomplete Military Transformation: Assessing the Weaknesses of the People's Liberation Army (PLA)*, Prepared for the U.S.-China Economic and Security Review Commission (Santa Monica, CA: RAND Corporation, February 2015), 14, https://www.uscc.gov/sites/default/files/Research/China%27s%20Incomplete%20Military%20Transformation_2.11.15.pdf.
23. GPS World Staff, "China Develops Ground-Based PNT Backup System with Nationwide Timing Network," *GPS World*, September 2021, https://www.gpsworld.com/china-develops-ground-based-pnt-backup-system-with-

China's theater-based forces, reinforcing asymmetries that undermine deterrence if left unaddressed. These asymmetries establish the criteria that any viable response to GPS denial must satisfy.

Effective responses to GPS denial must be scalable, interoperable, and deployable within relevant timelines. Solutions that are narrowly platform-specific, slow to field, or incompatible with allied systems risk fragmenting the joint force and undermining coalition effectiveness. Because deterrence depends on perception rather than technical performance alone, resilience solutions must be scalable and applicable across domains. Affordability, interoperability, and integration timelines therefore, constitute strategic variables rather than purely technical considerations. Only solutions that enhance coalition-wide resilience within relevant timelines can meaningfully contribute to credible deterrence in the Indo-Pacific.

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4 Quantum-PNT technology

Having established that deterrence effectiveness in the Indo-Pacific is determined by credibility, resilience, and coalition-wide operational performance under contested conditions, this chapter analyzes quantum Positioning, Navigation, and Timing (PNT) as a specific emerging technology that can mitigate vulnerabilities associated with GPS denial. Quantum technologies form a separate group of emerging capabilities with the potential to alter military operations by enabling new forms of sensing, computation, and information processing. Quantum science and technology are commonly grouped into three domains: quantum computing, quantum information, and quantum sensing.[24] While much public and policy attention focuses on quantum computing and encryption, quantum sensing has received less attention by comparison despite its direct military relevance.[25] Each quantum domain influences national security through different mechanisms. Quantum computing primarily affects data processing and cryptanalysis, quantum information enables secure communications and timing, and quantum sensing enhances measurement precision. This paper focuses on quantum sensing because it enables quantum-PNT. It encompasses onboard, passive navigation and timing systems that reduce reliance on external radio-frequency signals. By enabling assured navigation and timing without continuous satellite updates, quantum-PNT directly addresses vulnerabilities exploited by GPS jamming and spoofing, thereby affecting the credibility of military operations in contested environments. Understanding the military relevance of quantum-PNT requires placing it within existing

24. Kelley M. Sayler, *Defense Primer: Quantum Technology*, CRS Report / In Focus IF11836, Updated November 4, 2024 (Congressional Research Service (CRS), November 2024), https://www.congress.gov/crs_external_products/IF/PDF/IF11836/IF11836.14.pdf.

25. Mark P. Crawford, "Quantum Technology and the Military," *Expeditions with MCUP* 1, no. 3 (2023): 1–21, https://www.usmcu.edu/Outreach/Marine-Corps-University-Press/Expeditions-with-MCUP-digital-journal/Quantum-Technology-and-the-Military/.

navigation architectures and operational constraints.

Quantum-PNT does not replace Global Navigation Satellite Systems (GNSS), but complements them as an additional layer that improves resilience within a hybrid PNT architecture. GNSS remains indispensable for global civilian infrastructure and routine military operations.[26] However, reliance on space-based signals creates vulnerabilities in contested electromagnetic environments.[27] Quantum-PNT systems are inherently passive and do not emit signals that can be jammed or spoofed in the same manner as GNSS. Instead, they derive position and timing from precise measurements of inertial motion, gravitational fields, or magnetic anomalies. As a result, quantum-PNT primarily enhances resilience by reducing drift and preserving navigational accuracy during periods of GNSS denial, rather than by providing global coverage. In deterrence terms, quantum-PNT affects expectations of operational continuity under attack, thereby influencing adversary confidence in the effectiveness of denial strategies. Two principal technological approaches dominate current quantum-PNT research and development.

Quantum-PNT can be realized through cold-atom inertial sensing or anomaly-based navigation. Cold-atom interferometry exploits the wave-like behavior of ultra-cold atoms to achieve inertial measurements with substantially reduced drift compared to classical inertial navigation systems.[28] Anomaly-based navigation uses high-resolution gravitational or magnetic maps to correlate environmental signatures with platform location.[29] Cold-atom systems primarily

26. U.S. Government Accountability Office, *GPS Modernization: Better Information and Detailed Test Plans Needed for Timely Fielding of Military User Equipment*, GAO Report GAO-22-105086 (U.S. Government Accountability Office, May 2022), https://www.gao.gov/products/gao-22-105086.

27. Sayler, *Defense Primer: Quantum Technology*.

28. Senator Maggie Hassan and Senator Marsha Blackburn, “Letter to Secretary of Defense: Questions Regarding Quantum Sensing Initiatives,” Requested written response by November 15, 2024, October 2024, https://www.hassan.senate.gov/imo/media/doc/dod_quantum_sensing_letter.pdf.

29. Stockholm International Peace Research Institute, *Military and Security Dimensions of Quantum Technologies: A Primer* (Solna, Sweden: Stockholm International Peace Research Institute, July 2025), https://doi.org/10.55163/ZVTL1529, https://www.sipri.org/sites/default/files/2025-07/0725_military_and_security_dimensions_of_quantum_technologies_0.pdf.

improve the sensor itself by increasing measurement stability. Anomaly-based systems, on the other hand, use the environment as the navigation reference. Both approaches reduce dependence on external signals but introduce different constraints. This includes sensitivity to environmental noise, map fidelity, and computational requirements. Neither approach eliminates the need for GNSS, but both significantly extend the duration over which platforms can operate effectively without satellite updates. By reducing inertial drift and preserving navigation accuracy, quantum-PNT decreases the operational impact of GPS denial and complicates adversary planning for early-phase disruption. Despite their potential, quantum-PNT systems face significant practical constraints that shape their military utility.

The main limitation on near-term deployment of quantum-PNT is Size, Weight, Power, and Cost (SWaP-C). Current quantum sensors require specialized environments, precise control systems, and nontrivial power and cooling, limiting their suitability for small or expendable platforms.[30] As a result, early military adoption is expected to follow a tiered approach.[31] High-value platforms such as naval vessels, large aircraft, and strategic enablers are better positioned to absorb SWaP-C requirements than fighters, unmanned systems, or munitions. This tiered adoption resembles historical patterns in inertial navigation and other precision technologies. Accordingly, quantum-PNT should be understood as a selective resilience enhancer rather than a universally deployable solution in the near term. In terms of deterrence, even limited deployment on high-value platforms can have disproportionate effects by preserving command-and-control coherence and sustained power projection under contested conditions. Quantum-PNT development must also be understood within the broader international competitive

30. Sayler, *Defense Primer: Quantum Technology*.

31. Mark A. Suriano, *Robust Technology to Augment or Replace the US Reliance on the Global Positioning System*, Research Paper (Maxwell AFB, Alabama: Air War College, 2011), https://aul.primo.exlibrisgroup.com/permalink/01AUL_INST/995146933406836.

landscape.

Major powers are investing in quantum sensing for military applications, but with differing strategic emphases. China, the United States, and Russia all invest in quantum technologies, though they prioritize different domains based on strategic objectives.[32] China, in particular, integrates civilian and military quantum research through Military–Civil Fusion mechanisms.[33] These differing investment patterns reflect strategic intent rather than purely technological maturity. China's focus on sensing and timing aligns with its emphasis on countering U.S. advantages in precision warfare and satellite dependence. At the same time, timelines for mature, miniaturized quantum-PNT remain uncertain, creating the possibility of technological surprise. From a deterrence perspective, uncertainty surrounding quantum-PNT development underscores the importance of early integration and doctrinal adaptation rather than delayed adoption. Taken together, these characteristics clarify how quantum-PNT affects deterrence without deterministically producing it.

Quantum-PNT influences deterrence indirectly by shaping perceptions of operational resilience rather than by providing deterrence in isolation. Deterrence outcomes depend on adversary assessments of credibility, feasibility, and expected costs, rather than on the mere existence of advanced technology.[34] By reducing confidence in the effectiveness of GPS denial and early-escalation strategies, quantum-PNT alters the adversary's cost–-benefit calculations.

32. Hodan Omaar and Martin Makaryan, *How Innovative Is China in Quantum?*, Report. Available at: https://itif.org/publications/2024/09/09/how-innovative-is-china-in-quantum/ (Information Technology and Innovation Foundation (ITIF), September 2024), https://itif.org/publications/2024/09/09/how-innovative-is-china-in-quantum/.

33. Ajey Lele, "Military Relevance of Quantum Technologies" [in eng], Advanced Sciences and Technologies for Security Applications (Switzerland: Springer International Publishing AG, 2021), 117–143, ISBN: 3030727203, https://doi.org/10.1007/978-3-030-72721-5_8.

34. Robert Powell, *Nuclear Deterrence Theory: The Search for Credibility* (Cambridge: Cambridge University Press, 1990), ISBN: 9780521385869, https://doi.org/10.1017/CBO9780511625045.

However, it does not remove all vulnerabilities and does not negate the political nature of deterrence. Its strategic value lies in reinforcing denial and punishment mechanisms already embedded in alliance structures and operational plans. Quantum-PNT should therefore be understood as a resilience-enabling technology that supports credible deterrence when integrated deliberately, rather than as a standalone deterrent capability.

5 How sharing quantum technology can shape Indo-Pacific dynamics

Having established that quantum-PNT can enhance operational resilience under GPS-denied conditions, this chapter examines how the controlled sharing of such technology can shape deterrence dynamics in the Indo-Pacific by influencing alliance cohesion, political commitment, and credibility.

Technology sharing can serve as a tool within alliances by creating perceptions of commitment, cohesion, and long-term strategic alignment. Strategic competition increasingly depends on alliances' ability to generate collective resilience across security, economic, and technological domains.[35] In alliance contexts, the strategic value of technology sharing lies not only in improved military effectiveness but also in the political messages it sends. Sharing sensitive enabling capabilities imposes costs and risks on the provider, thereby signaling resolve and long-term commitment. Conversely, withholding such capabilities can strengthen perceptions that support is conditional or hierarchical within alliances, which adversaries may seek to exploit. From a deterrence perspective, technology sharing affects credibility by shaping adversary beliefs about alliance durability and the likelihood of coordinated action under stress. These signaling effects are particularly salient for resilience-enhancing technologies such as quantum-PNT.

Controlled sharing of quantum-PNT with selected Indo-Pacific allies can strengthen deterrence by denial. Quantum-PNT enables assured navigation and timing under contested electromagnetic conditions by reducing reliance on vulnerable space-based signals. If coalition

35. Hal Brands, *The Twilight Struggle: What the Cold War Teaches Us about Great-Power Rivalry Today* (Yale University Press, 2022), ISBN: 9780300250787, accessed November 18, 2025, http://www.jstor.org/stable/j.ctv270kvpm.

forces can maintain operational coherence despite attempts to disrupt PNT, China's confidence in achieving rapid or limited objectives decreases. This undermines strategies that rely on early denial, coalition disintegration, or temporary operational paralysis. Unlike forward force posture expansion, resilience-based improvements do not require highly visible or escalatory commitments from allies. By strengthening deterrence by denial without proportionally increasing political exposure, quantum-PNT sharing provides a way to reinforce stability while managing escalation risks. Beyond denial, technology sharing also influences deterrence by punishment.

Sharing quantum-PNT can enhance deterrence by punishment by expanding the coalition's ability to impose costs. Deterrence by punishment depends on the perceived ability to impose unacceptable costs following aggression.[36] When multiple allied platforms retain precision, coordination, and targeting capability under degraded conditions, the number of credible retaliation pathways increases. This complicates adversary planning and raises expected costs across kinetic and non-kinetic domains. Sustained PNT functionality preserves the integrity of the entire targeting chain rather than individual weapon systems. Quantum-PNT sharing strengthens punishment-based deterrence by increasing the scale, resilience, and credibility of coalition response options. Technology sharing also carries important political and strategic implications beyond immediate operational effects.

Sharing quantum-PNT signals political commitment and reduces incentives for alliance decoupling. Adversaries routinely seek to weaken alliances by applying selective political and economic pressure to individual members.[37] Providing advanced resilience technologies increases

36. Schelling, *Arms and Influence*, 69.
37. Barry Murdaco, "The Political Economy of U.S. Containment: China's Response, Imperial Legacies, and U.S.-China Relations," *Science & Society* 89, no. 4 (2025): 535–560, https://doi.org/10.1177/00368237251359252.

the political cost of disengagement for both providers and recipients. It builds cooperation into long-term planning, training, and sustainment relationships, making alliance fragmentation more difficult to achieve. These dynamics are consistent with Brands's argument that durable alliances require deep integration across multiple domains, not episodic cooperation.[38] Quantum-PNT sharing reinforces deterrence by strengthening alliance credibility, cohesion, and long-term strategic cooperation.

38. Brands, *The Twilight Struggle: What the Cold War Teaches Us about Great-Power Rivalry Today*.

6 Quantum-PNT as a specific case study

This chapter examines quantum-PNT as a concrete case study to assess how emerging technologies can influence deterrence when integrated within an alliance-based framework rather than held exclusively at the national level.

Exclusive possession of advanced PNT capabilities is not enough to address coalition-wide vulnerability to GPS denial. Modern U.S. and allied military platforms rely heavily on inertial navigation systems that degrade over time without reliable external synchronization. Even if U.S. platforms achieve improved resilience, deterrence remains vulnerable if allied forces are unable to operate effectively under GPS-denied conditions. Selective coercion against less resilient coalition members can undermine collective action and create opportunities for limited aggression. As a result, resilience gains achieved by the United States alone do not fully translate into deterrence at the coalition level. Deterrence effectiveness in alliance contexts, therefore, depends on shared resilience rather than isolated technological advantage. Quantum-PNT sharing offers a mechanism to address this coalition vulnerability directly.

Sharing quantum-PNT with key Indo-Pacific allies strengthens deterrence by denial, punishment, and political commitment. Quantum-PNT enables sustained navigation and timing performance under contested electromagnetic conditions. Assured PNT preserves operational coherence, supports joint command-and-control, and sustains credible strike options. By reducing the effectiveness of GPS denial as a coercive tool, shared quantum-PNT increases uncertainty regarding the feasibility, timing, and costs of aggression. At the same time, it increases the coalition's ability to impose costs across domains by retaining the integrity of targeting and coordination. Quantum-PNT sharing strengthens deterrence by limiting efforts to disrupt weaker coalition members. These benefits must be balanced against the risks inherent in technology sharing.

Sharing quantum-PNT introduces significant risks that can be managed. Advanced military technologies face risks of proliferation, reverse engineering, unauthorized re-export, and political exposure. These risks can be mitigated through black-box architectures, anti-tamper mechanisms, restricted interfaces, and governance arrangements that preserve control over sensitive components. While risk cannot be eliminated, it can be reduced to levels comparable with existing alliance technology-sharing practices. When managed appropriately, the deterrence benefits of shared resilience outweigh the risks associated with controlled quantum-PNT sharing. Understanding likely adversary responses is essential to evaluating the overall effect on deterrence.

China is likely to respond to quantum-PNT sharing through political, economic, and technological countermeasures. China has historically responded to perceived containment by applying pressure across diplomatic, economic, and technological domains.[39] Such responses may include efforts to discourage participation, offer alternative technological partnerships, or target alliance cohesion. However, a coalition with assured PNT is less vulnerable to short-notice aggression and targeted political and economic pressure. All this reduces the effectiveness of these countermeasures. Even under active Chinese opposition, shared quantum-PNT strengthens extended deterrence by limiting exploitation of coalition vulnerabilities.

39. Murdaco, "The Political Economy of U.S. Containment: China's Response, Imperial Legacies, and U.S.-China Relations."

7 Policy recommendations

The preceding analysis demonstrates that traditional approaches to technology protection are no longer well aligned with current strategic realities of deterrence and alliance management in the Indo-Pacific.

U.S. quantum-PNT policy should shift from technological exclusivity toward carefully managed technology sharing with selected Indo-Pacific allies. China's growing ability to approach parity in selected technology domains reduces the effectiveness of exclusivity-based strategies.[40] Withholding quantum-PNT from allies does not prevent Chinese advances but preserves coalition-wide vulnerability to GPS denial. Controlled sharing enhances operational coherence and limits opportunities for selective coercion against less resilient partners. The policy objective should therefore prioritize coalition effectiveness under contested conditions rather than unilateral technological advantage. Shifting toward controlled sharing strengthens deterrence by denial and punishment while reinforcing alliance credibility. Timing and geographic focus are critical to the effectiveness of this policy shift.

The United States should act early and prioritize quantum-PNT integration in the Indo-Pacific theater. Quantum-PNT technologies require long development, integration, and standardization timelines. Delaying decisions until full technological maturity risks losing strategic relevance, as alliance integration and trust cannot be developed quickly during a crisis. Early coordination enables standardization, reduces implementation friction, and signals durable commitment to regional partners. Focusing on the Indo-Pacific is warranted because GPS denial and counter-C5ISR strategies are most salient there. By acting early and regionally, the United

40. Omaar and Makaryan, *How Innovative Is China in Quantum?*

States can strengthen deterrence by denial, sustain credible punishment options, and reduce the strategic effectiveness of Chinese GPS denial.

8 Conclusion

This paper has argued that sustaining extended deterrence in the Indo-Pacific requires the United States to move beyond a heavy reliance on space-based systems and restrictive technology policies toward a coalition-focused approach to resilience. Specifically, it has demonstrated that controlled sharing of quantum-enabled Positioning, Navigation, and Timing (PNT) with selected Indo-Pacific allies can strengthen deterrence by denial and deterrence by punishment by preserving coalition operational effectiveness under GPS denial, while simultaneously reinforcing alliance credibility through visible, long-term commitment.

The analysis began by establishing that deterrence is fundamentally political and driven by credibility, and that vulnerabilities in critical enabling functions such as PNT can translate directly into strategic risk. Applied to the Indo-Pacific, GPS denial creates asymmetric costs that favor China, driven by geography, force posture, and a more resilient PNT ecosystem. Quantum-PNT was examined as a resilience-enhancing technology that does not provide deterrence on its own, but that influences adversaries' perceptions by reducing confidence in early-phase denial strategies. The paper then showed that technology sharing can serve as an alliance instrument, signaling commitment and cohesion while mitigating selective coercion against less resilient partners. As a case study, quantum-PNT illustrated how shared resilience, rather than exclusive technological advantage, better supports coalition deterrence. Finally, the policy recommendations argued for early integration, with a focus on the Indo-Pacific, and for controlled sharing as a means to strengthen deterrence without unnecessary escalation.

The historical lesson invoked at the outset, "the bomber will always get through", is intended as a warning rather than a rhetorical device. Just as faith in the inevitability of bomber penetration proved vulnerable to adaptation, contemporary confidence in assured GPS-enabled operations risks similar erosion under adversary countermeasures. Deterrence in the Indo-Pacific will therefore hinge not on preserving the assumption that technology will always prevail. Instead, it will hinge on denying adversaries confidence that disruption of a single enabling function can undermine coalition effectiveness. By treating quantum-enabled PNT as a shared resilience enabler rather than a guarded advantage, the United States can develop a deterrence posture that can adapt more quickly than China can undermine it.

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