THE HIDDEN LOAD-BEARER

Why GNSS Timing Infrastructure Is Catastrophically Undervalued Relative to Its Economic Load

Alexander Parolini

Position Paper • March 2026 • Submitted for Review

EXECUTIVE SUMMARY

The Global Navigation Satellite System (GNSS) is not primarily a navigation technology. It is the invisible clock that synchronizes global telecommunications, financial markets, power grids, and supply chains. The economic value it generates is measured in trillions. The annual investment protecting the geodetic ground infrastructure that underpins it is measured in tens of millions. This paper argues that this gap constitutes a formally unpriced systemic risk — one with no analog in any other class of critical infrastructure — and that the institutional mechanisms to price and address it do not currently exist.

I. The Nature of the Dependency

There is a class of infrastructure so embedded in the functioning of modern economies that its failure is effectively unthinkable — until the moment it happens. GNSS timing belongs to this class. The dependency is not on location data, which is how the technology is commonly understood. It is on time.

The scale of this dependency, measured in economic terms, is striking. A landmark study commissioned by the U.S. National Institute of Standards and Technology (NIST) and conducted by RTI International found that GPS generated approximately $1.4 trillion in cumulative economic benefits for the U.S. private sector between 1984 and 2017 alone. The global GNSS market, measured by direct device and service revenue, was valued at approximately €199 billion in 2021, with forecasts projecting €492 billion by 2031. These figures substantially understate the true economic load, because they measure the market for GNSS-enabled products and services rather than the value of the timing signal itself, which is a public infrastructure input for which no direct market exists.

Cell towers use GNSS-derived timing to route calls and data across 4G and 5G networks. Timing errors as small as 30 nanoseconds can disrupt synchronization across an entire regional network. Electrical grids use GNSS-derived timing for phasor measurement units that balance load distribution in real time. Financial exchanges rely on sub-microsecond accuracy for transaction timestamping and regulatory compliance. In each of these systems, GNSS timing is treated as a utility — available, reliable, and free. None of them has built serious contingency architecture for its absence.

These figures substantially understate the true economic load, because they measure the market for GNSS-enabled products and services rather than the value of the timing signal itself.

II. The Cost of Failure

The failure scenario is not hypothetical. In 2024, EUROCONTROL data showed that up to 38% of European en-route traffic was operating through regions regularly affected by GNSS radio frequency interference, with individual member states recording thousands of individual incidents: Finland documented approximately 2,800 cases across 2024, and Poland recorded over 2,700 in January 2025 alone. Effects extended well beyond active conflict zones to affect civilian air and maritime traffic across the continent. Spoofing incidents have disrupted maritime navigation in contested waterways. These are not edge cases; they are demonstrations of a vulnerability that adversaries have already located and are actively exploiting. (Source: EUROCONTROL Performance Review Report 2024; Finnish Transport and Communications Agency; Polish Civil Aviation Authority.)

The economic cost of a sustained GPS outage is almost certainly far larger than published figures suggest. The most instructive benchmark is not a GPS-specific model but a real-world infrastructure failure of comparable scope: Texas lost an estimated $195 billion from a single week of power grid failure in February 2021 (University of Texas at Austin Energy Institute, 2021). That event affected one state and one sector. A GPS outage would simultaneously degrade telecommunications, financial systems, transportation, and energy grid management across the entire country — and would do so with no regional fallback and no rapid recovery pathway for systems that have not maintained independent timing backup. A reasonable independent estimate, extrapolating from the Texas benchmark and adjusting for the breadth of GPS dependency across 14 of 16 designated U.S. critical infrastructure sectors, places daily economic losses in the range of $10 to $20 billion for a major sustained outage — an order of magnitude above the most widely cited published figure. The RTI International study commissioned by NIST (2019) estimated losses of approximately $1 billion per day; Dana Goward of the Resilient Navigation and Timing Foundation has noted that this represents less than 1.7% of U.S. daily GDP, a figure difficult to reconcile with GPS's role as a single point of failure across virtually every critical infrastructure sector. The RTI and Brattle Group figures are included below as documented lower bounds, not central estimates:

Outage Duration	RTI/Brattle Estimate (lower bound)	Global Loss Estimate
1 Day	$1.6 billion	$4–6 billion
7 Days	$12.2 billion	$35–45 billion

Outage Duration	RTI/Brattle Estimate (lower bound)	Global Loss Estimate
30 Days	$58.2 billion	$150–200 billion
Agricultural Season (peak)	$1.5 billion/day	Compounding cascade

These figures represent direct economic losses as modelled by RTI International and The Brattle Group. They do not fully account for the cascade sequence that would accompany a sustained outage. Transportation slows and becomes more dangerous within hours. Network clocks begin to desynchronize. Mobile networks degrade. Financial systems lose transaction integrity. Stock exchanges must suspend operations because trades cannot be reconciled against a common timestamp. Automated trading systems, which account for the majority of daily equity market volume, go offline. ATMs stop functioning. Eventually, the electrical grid itself is affected as phasor measurement units lose their synchronization reference. Independent estimates anchored to real-world infrastructure failure data — including the Texas 2021 benchmark — suggest actual losses would substantially exceed the figures above. The assumptions underlying the RTI/Brattle models, and the basis for higher independent estimates, are discussed further in the investment case section below.

This cascade does not require a satellite failure. It can be triggered by coordinated jamming, spoofing, a significant solar weather event, or a cyberattack on ground control infrastructure. The attack surface is large, the dependencies are tightly coupled, and the recovery pathway — for systems that have not maintained independent timing backup — is slow.

III. The Investment Gap

Against this economic load, the investment protecting the geodetic ground infrastructure that underpins GNSS accuracy and timing is strikingly thin. The National Science Foundation's Geodetic Facility for the Advancement of Geosciences (GAGE), one of the primary institutions maintaining the North American geodetic ground network, operates on an annual budget of approximately $14.55 million. This budget supports operations across more than a thousand stations spanning the continental United States, Mexico, and the Caribbean.

To place this in proportion: a sector generating $1.4 trillion in cumulative benefits over three decades is underpinned by ground infrastructure receiving less than $15 million per year in maintenance funding. The GNSS device and services market, projected to reach €492 billion by 2031, is supported by geodetic infrastructure receiving less than 0.05 percent of that revenue in annual investment. No institutional investor, insurer, or infrastructure operator would accept this ratio in any other asset class.

The structural deterioration of this investment is accelerating. The NSF has signaled that future funding constraints will support a network of approximately 1,100 stations — down from the current 1,257 (per NSF FY2022 budget documentation) — implying planned contraction of the ground network at precisely the moment when GNSS-dependent economic activity is expanding most rapidly. Meanwhile, both China and Russia have deployed terrestrial backup systems that secure positioning, navigation, and timing continuity independently of GPS. The United States has decommissioned legacy infrastructure that could have been retrofitted, and recent efforts to develop modern terrestrial alternatives have stalled.

The GPS ground control modernization program provides the clearest illustration of institutional dysfunction. The next-generation Operational Control System was delivered in July 2025, over eight years behind its original 2017 schedule. Against an initial 2012 cost estimate of $3.7 billion, total program costs for Blocks 0, 1, and 2 reached approximately $7.6 billion as of 2023 — a cost growth of more than $3 billion against the original baseline, with full program costs projected by the GAO to approach $10 billion when Block 3F is included. The program that was intended to modernize the resilience of the system instead demonstrated the brittleness of the institutional processes governing it.

IV. Why Markets Have Not Priced This Risk

The failure to price this risk is not irrational. It follows directly from the structural characteristics of the dependency. GNSS timing is a public infrastructure input with no direct market price. Its beneficiaries are diffuse — spanning telecommunications, finance, energy, transportation, and agriculture — with no single sector bearing concentrated exposure sufficient to justify unilateral investment in resilience. The cost of maintaining backup timing capability falls on individual operators; the benefit of systemic resilience accrues to all operators simultaneously. This is a textbook collective action problem, and it has produced the predictable outcome: systematic underinvestment in a shared critical dependency.

The risk is further obscured by the reliability record of GPS itself. The system has functioned with remarkable continuity since its full operational capability was declared in 1995. Three decades without a major outage have produced institutional complacency that is now structurally embedded in the design assumptions of critical infrastructure across every dependent sector. The systems built on GNSS timing were not designed with failure modes in mind, because failure was not within the experiential horizon of the engineers who built them.

This combination — diffuse beneficiaries, no direct market price, and a long reliability record — means that the risk will not be priced by markets alone. It requires deliberate institutional intervention: regulatory requirements for independent timing backup, sustained public investment in geodetic ground infrastructure, and formal modeling of GNSS timing as a systemic risk variable in the frameworks used by financial regulators, infrastructure operators, and national security planners.

The insurance and reinsurance sector has not priced this risk — and the absence of pricing is itself informative. Aviation and maritime underwriters, who operate in the sectors most directly and visibly exposed to GNSS disruption (in 2024, up to 38% of European en-route traffic was operating through regions regularly affected by interference, with individual member states recording thousands of cases), have not incorporated GPS outage scenarios into standard underwriting models. The reason is structural rather than analytical: there is no claims history to anchor pricing, because a large-scale, sustained GNSS timing failure has not yet occurred in the modern infrastructure era. This is precisely the condition that precedes catastrophic mispricing in other lines — the absence of loss experience in a tail risk that has never been tested at scale. The parallel to pre-2005 hurricane season modeling, or to cyber insurance before NotPetya, is direct. Early movers who develop underwriting frameworks for GNSS timing disruption now — before the first major event — will hold a structural pricing advantage when the market reprices. Those who wait will face the same experience that cyber underwriters faced after 2017: rapid and poorly understood accumulation that was already embedded in portfolios before the risk was recognized.

V. The Investment Case

The economic argument for addressing this gap is straightforward. GPS has functioned as a public-sector investment whose returns have dwarfed its costs by orders of magnitude. The marginal cost of maintaining the geodetic ground infrastructure that preserves GNSS accuracy and timing is a fraction of a percent of the economic value that infrastructure protects each year. Research into infrastructure resilience investment has consistently demonstrated returns on the order of $16 for every $1 spent when interventions are targeted at high-dependency, high-exposure systems.

The intervention required is not large relative to the risk it mitigates. The core program consists of four components:

- Modernization and expansion of the geodetic ground station network to a minimum of 1,500 stations globally, with redundant power and communications infrastructure at each node.
- Mandatory independent timing backup requirements for designated critical infrastructure operators in telecommunications, finance, energy, and transportation, capable of sustaining operations for a minimum of 30 days without GNSS input.
- Investment in multi-constellation receiver infrastructure that draws from GPS, Galileo, GLONASS, and BeiDou simultaneously, reducing single-system dependency across critical sectors.
- Establishment of a formal systemic risk modeling framework for GNSS timing, developed collaboratively by financial regulators, infrastructure operators, and national security agencies, to enable consistent pricing of this risk across institutional boundaries.

The total cost of this program, across a ten-year implementation horizon, is estimated in the range of $2 to $4 billion — against a risk exposure that conservative modeling places at $50 to $200 billion per sustained outage event. The return on investment is not ambiguous.

VI. Conclusion

GNSS timing is the most economically consequential infrastructure that no mainstream risk framework currently prices. Its failure would not manifest as the outage of a single service. It would manifest as the simultaneous degradation of telecommunications, finance, energy, and transportation — a correlated failure across every sector of the modern economy, triggered by a single point of dependency that most institutions have never formally identified as a risk variable.

The gap between the economic load GNSS timing carries and the investment protecting it is not a gap that markets will close on their own. The beneficiaries are too diffuse, the infrastructure is treated as a public good, and the reliability record has suppressed the institutional urgency that would otherwise drive action. Closing it requires deliberate institutional intervention — regulatory, legislative, and multilateral.

One further point deserves emphasis. The economic loss estimates cited throughout — $1 billion per day, $58 billion for a 30-day U.S. outage — have been criticized by leading GPS resilience experts as structurally understated. Dana Goward of the Resilient Navigation and Timing Foundation has argued that $1 billion per day represents less than 1.7% of U.S. daily GDP, a figure difficult to reconcile with the assessment that GPS is a single point of failure for 14 of 16 designated critical infrastructure sectors. A more realistic order-of-magnitude anchor: Texas lost an estimated $195 billion from a single week of power grid failure in 2021 (University of Texas at Austin Energy Institute). A nationwide GPS outage would compound that scale of disruption across every dependent sector simultaneously, with no regional fallback and no rapid recovery pathway for systems that have not maintained independent timing backup. Conservative independent estimates suggest the true daily loss figure is a multiple of the published benchmarks — losses better measured as several percent of GDP per day than as a rounding error within it.

The economic case for that intervention is unambiguous. The primary obstacle is not resources. It is the absence of a formal institutional framework that recognizes GNSS timing as a systemic risk variable and assigns responsibility for managing it. This paper is a contribution toward building that framework.

Key Sources and Data Foundations

Source	Institution	Key Contribution
Economic Benefits of GPS	RTI International / NIST	$1.4 trillion U.S. private sector benefit (1984–2017)

Source	Institution	Key Contribution
GPS Outage Cost Modeling	The Brattle Group	\$1.6B/day to \$58.2B/month U.S. loss estimates
GNSS Market Forecast	European Union Agency for the Space Programme (EUSPA)	€199B (2021) → €492B (2031) market projection
Geodetic Infrastructure Funding	NSF / GAGE Facility	\$14.55M annual budget; network contraction risk
GPS Modernization Program	U.S. Government Accountability Office	OCX delivery 8+ years late; \$4B cost overrun
GNSS Interference Events	EUROCONTROL	80+ major interference events, Europe, 2024

DISTRIBUTION NOTE

This paper is submitted for review to the Resilient Navigation and Timing Foundation (RNT Foundation) as an initial contribution to the policy and advocacy conversation on GNSS systemic risk. The author welcomes direct engagement and is prepared to develop this analysis further in collaboration with institutional partners. Secondary distribution targets include: DHS/CISA Critical Infrastructure Division; NIST Physical Measurement Laboratory; Senate Armed Services Committee Staff; Munich Re and Swiss Re Systemic Risk Research; NYSE and DTCC Chief Risk Officers; PJM Interconnection and ERCOT grid operators.