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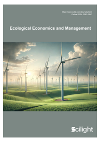

Letter

Economic and Operational Implications of the Leap Second and Its Cancellation

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Abstract: Leap seconds are one-second adjustments added to Coordinated Universal Time (UTC) to keep it within ±0.9 s of Earth's rotational time (UT1), i.e., to synchronize atomic time with astronomical time. Since 1972 there have been 27 positive insertions, the last on 31 December 2016. In November 2022 the General Conference on Weights and Measures (CGPM) adopted a path to phase out future leap seconds by or before 2035, moving toward a continuous UTC. This article consolidates documented operational incidents and presents a back-of-the-envelope economic assessment of leap-second events. We find that a single leap second plausibly exposes the global economy from the low tens of millions up to about USD 100 million in direct disruptions, with tail risks concentrated in finance, aviation, and large-scale internet platforms. Removing the leap second reduces coordination burden and eliminates a rare but brittle failure mode—especially salient given the prospect of a possible first-ever negative leap second.

Keywords: universal time; time synchronization; timestamps; UTC; leap second; trade control; resilience

1. Background and Current Status

Coordinated Universal Time UTC, the time we use on Earth, is realized from atomic time (Temps Atomique International, TAI) with occasional discontinuities (integer-second offsets) so that the absolute value of the difference from Earth's rotational time, called UT1, remains smaller than 0.9 s (in short, to synchronize atomic time with astronomical time). These occasional offsets are called "leap seconds". Leap seconds are irregular because Earth's rotation is irregular. The rotation speed of the Earth varies because of astronomical effects such as tidal forces from the Moon and the Sun, and geological processes such as mantle convection, earthquakes, glacial rebound, and the redistribution of mass in the oceans, atmosphere, and ice sheets. The assumption that the Earth makes a complete rotation in 24 hours (86,400 s) is, thus, only an approximation, although rather precise. As of mid-2025, $\mathrm{TAI} - \mathrm{UTC} = 37\,\mathrm{s}$ [1]. A total of 27 positive leap seconds were added between 1972 and 2016 [2], no negative leap second has been needed up to now, and no leap second has been scheduled for the end of 2025 [1]. The idea is that we adjust the time so that, on average, the Sun culminates at the Greenwich meridian within 0.9 seconds of 12:00:00 UTC. For historical context on leap seconds, see e.g., [3].

Besides its importance in fundamental science, leap seconds touch domains that underpin modern society, in particular:

- The interoperability of digital infrastructure. Telecom networks, satellite navigation systems, financial exchanges, and distributed databases depend on a shared notion of "now"; even a single extra second can trigger replay protection failures, time-window mismatches, or log-order inversions if it is not handled consistently.
- Traceability and auditability. Scientific experiments, safety systems, and legal records often require synchronization and timestamps that are reproducible now, and years later.

At the same time, leap seconds introduce engineering challenges because they are irregular and not precisely predictable given our current knowledge of Earth's geophysics and Solar System dynamics, announced only months in advance, and there is no universal strategy to implement them. Operators must therefore choose among different strategies—*step* (a one-second jump), *slew* (gradual frequency adjustment), or *smear* (distributing the extra second over an interval)—each with distinct failure modes. Past events have exposed this fragility: widely reported service degradations followed the 2012 leap second, and additional care was required for the 2015 and 2016 insertions.

The BIPM (Bureau International des Poids et Mesures) is the intergovernmental organization that ensures the uniformity of the world's measurement system, the Système International (SI). Founded in 1875 by the Metre Convention, it is one of the oldest international organizations, and it is based at the Pavillon de Breteuil in Sèvres, near Paris. The measurement of time is fundamental, and the BIPM calculates and distributes the universal time UTC. The CGPM (Conférence Générale des Poids et Mesures) is the decision-making body of the BIPM, an assembly of the Member States meeting every four years. It sets policy and defines the SI, including the definition of the second.

In 2022, the 27th CGPM voted to allow UTC to remain continuous starting from 2035 or before, with details to be finalized on the allowed magnitude of the difference $|\mathrm{UT1} - \mathrm{UTC}|$ [4]. The World Radiocommunication Conference 2023 (WRC-23) subsequently recognized this direction, reinforcing international alignment [5, 6].

What are the economic implications of the decision, and what should be the tolerance on the correspondence between atomic and astronomical time?

2. Why Leap Seconds Are Operationally Costly

A one-second discontinuity breaks implicit assumptions in distributed systems: timestamps may repeat or go backward, timers can stall, and consensus or ordering guarantees may be violated. Workarounds such as "smear" profiles—spreading the one-second UTC adjustment over many hours so clocks never jump—are used by major providers to keep distributed systems continuously evolving; these reduce risk but increase complexity and require cross-vendor coordination [7].

Maintaining the leap second practice has imposed real costs, risks, and complexities across various sectors, from finance and telecommunications to defense. Because leap seconds occur at irregular intervals and with limited warning, they require continual vigilance, software updates, and sometimes manual intervention in critical systems.

Documented incidents illustrate the fragility of leap seconds. In July 2012, the leap second triggered failures in the Amadeus flight reservation system, delaying more than 400 Qantas flights [8, 9]. On 30 June 2015, sporadic internet outages were reported across networks during the leap-second event [10]. On a smaller scale, astronomers (one of the authors is an astrophysicist) experience that, because telescopes must be synchronized, leap second events turn observatories into mild-chaos zones for a day. Financial infrastructures mitigate risk by altering schedules: in 2015 the CME Group issued specific Electronic Trading and Clearing advisories [11, 12], and the London Stock Exchange Group – Turquoise provided operational guidance [13]. The U.S. National Institute of Standards and Technology NIST published Best Practices for the 2015 event to help operators prepare [14].

Below, we examine key examples of the economic and operational impacts in different industries.

3. Order-of-Magnitude Economic Assessment

Because firms rarely disclose outage costs, only coarse, literature-anchored estimates are feasible. Economic and operational impacts include:

3.1. Financial Services

In high-speed trading, even a one-second skew can matter. Not all platforms and exchanges necessarily apply the leap second at exactly the same instant or in the same way, raising the nightmare scenario of trades being timestamped out of order or even executed "before" their official time. A commentary in Finextra [15] warned that the chaos of unsynchronized clocks and system glitches around a leap second "has the potential to cost the [financial] industry tens of millions of pounds" in errors or downtime. In practice, exchanges have taken drastic preventive steps. For example, during the June 30, 2015, leap second event, major stock markets altered their schedules to avoid any mishaps: Nasdaq ended extended-hours order entry at 19:30 ET, trade actions at 19:50 ET, and declared system unavailable at 19:55 ET; NYSE/NYSE-Arca closed their extended session at 19:30 ET; ICE Futures Europe delayed all market-state transitions from 23:00 to 00:01 GMT (61 min). These measures carry opportunity costs–brief halts or early closes can equate to millions in foregone volume. One analysis noted that just one second of full market outage on a major exchange can cost on the order of $ 4.5 million in lost trade volume, based on average trading throughput. Thus, beyond direct technical expenses, leap seconds threaten to undermine market efficiency and trust if not handled perfectly. The need to coordinate global market responses to leap seconds (including out-of-band fixes and communication with clients) is itself an operational overhead that the finance industry has had to contend with every few years [11–13].

3.2. Telecommunications and IT Systems

Distributed systems must agree on time; otherwise, timestamps can move backward or duplicate, potentially crashing databases, breaking software, or causing certificates to "expire" incorrectly. Implementations and preparations are documented by NIST and industry players [7, 14]. To mitigate risks, companies like Google, Meta, Amazon and others have developed custom time smearing solutions, wherein the extra second is not inserted in one chunk but gradually spread out. However, during the June 2012 leap second, a subtle bug in the Linux operating system's kernel timer handling was triggered by the 23:59:60 timestamp, causing high-profile services to crash. Besides the Amadeus/Qantas operations crash already described, major websites and platforms including Reddit, LinkedIn, Yelp, Gawker, and Mozilla froze or went down due to this bug [8–10].

3.3. Defense and Critical Infrastructure

Certain specialized systems incur particularly large expenses to mitigate leap second risks because the stakes are high. A striking example is in national security: the U.S. military reportedly puts its entire nuclear command-and-control network in a special precautionary mode for an hour before and after each scheduled leap second. This effectively freezes any critical timestamp-dependent operations to avoid confusion from the extra second. The cost of this procedure has been cited as a "two-digit-million-dollar" expense for every leap second event. In the words of one commentary, "Mutually assured destruction is down for scheduled maintenance" during that period – a darkly humorous illustration of how even defense systems cannot fully trust their automated processes to handle an unexpected second.

Other infrastructure sectors face similar concerns. Power grids and energy utilities rely on precise timestamping for monitoring grid stability and fault detection; if different devices disagree on time by even a second, it could interfere with automated protection mechanisms or confuse data logs. Industrial control systems, transportation networks, and telecommunications backbones all require tightly coordinated time. A leap second can act as a small but non-negligible shock to these systems, one that must be anticipated and tested. A U.S. government official noted that because leap seconds cannot be predicted far in advance, computer systems and telecommunications networks around the world must be adjusted manually, and these occasional UTC adjustments have caused glitches over the years, citing the 2012 outages and flight delays as examples. In short, operators of critical infrastructure often take a very conservative approach to leap seconds—including complete system freezes or manual oversight, which carries direct costs (in manpower, downtime, and reduced service) every time a leap second occurs [11–14].

3.4. General Operational Overhead

Leap-second announcements (typically with six months' notice from the International Earth Rotation and Reference Systems Service, IERS) trigger global patches and configuration updates [1, 14]. Industry studies on downtime costs (e.g., Ponemon/Vertiv) provide unit-cost benchmarks; aviation delay cost baselines are available from Airlines for America [16, 17].

From Table 1 we can see that even using conservative, documented figures, a single leap-second event can push a cost on the order of $50 M, with a plausible range from $20 M to $100 M, in global, direct economic exposure, with the highest risk concentrated in defense, ultra-low-latency finance, and internet backbone operations. Eliminating leap seconds therefore removes a recurring, eight-figure drag on the world economy every time Earth's rotation drifts by a second.

Table 1. Representative sectoral exposures for a leap-second. M = million; all amounts in USD ($).

Sector/Representative System	**Published Evidence of Impact**	**Cost for One Leap-Second Event**	**How the Figure Was Derived**
National-defense/nuclear deterrent network	Operators commonly enter special change-control/hold modes around events [14]	≈$50 M (10–99 M range)	Based on typical high-criticality change windows; enterprise downtime unit-cost ranges [16].
Capital-markets trading	Exchanges/clearing operations issue special notices and adjust schedules [11–13]	$4.5 M–$25 M	Lower bound uses per-second downtime heuristics; upper bound reflects tens-of-millions-class risk [11–13]

Table 1. *Cont.*

Sector/Representative System	Published Evidence of Impact	Cost for One Leap-Second Event	How the Figure Was Derived
Commercial aviation (2012 Qantas/Amadeus)	400 flights delayed; leap-second Linux bug identified [8, 9]	\$1.2 M–\$4.8 M (mid-case ≈ \$2.4 M)	400 flights × (30–120 min) × \$∼100/min using 2024 delay-cost baseline [17]
Global Internet/Telco backbone	Sporadic outages in 2015 event [10]	\$10 M–\$100 M	Event reports combined with enterprise downtime unit-cost benchmarks [10, 16]
Enterprise IT (per firm)	Short mitigations/windows common	\$9 k–\$28 k per firm	Based on Vertiv downtime costs for 1–5 minutes [16]

4. The "Negative Leap Second" Risk, the 2022 CGPM Decision, and the Discussion at 2025 CIPM

The 27th CGPM resolved to move toward a continuous UTC by or before 2035, removing routine 1 s steps [4]. A key motivation is the novel possibility of a negative leap second—skipping 23:59:59—due to the recent acceleration in Earth's rotation. As this would be the first negative leap second, there is widespread concern that equipment—especially legacy systems, which may be unprepared and never tested for this scenario—may not handle it correctly; industry preparation might be comparable to the millennium bug (Y2K), with potential costs in the hundreds of millions.

The *Nature* magazine reported extensively on the context [6] in 2022; more recently, Agnew (2024) explained how polar ice-melt mass redistribution likely postpones the possible need for a negative leap second to 2029 and possibly beyond [18].

Finally, in October 2025, the Comité International des Poids et Mesures (CIPM), the governing body of the BIPM, reviewed progress towards a continuous UTC and agreed to bring a draft resolution to the 28th CGPM (scheduled in October 2026) defining a new maximum tolerance for the difference between UT1 and UTC, and an implementation plan. At the next CGPM it will be probably proposed increasing the permitted discrepancy between astronomical time and atomic time from 1 second to 1 hour. At the current rate of change of the Earth's rotational speed, this should ensure the stability of time for a period between one thousand and ten thousand years. In practice, if the proposal is approved, the "leap second" will be abolished.

5. Conclusions and Recommendations

Based on documented incidents and industry benchmarks, a single leap-second event plausibly exposes the global economy to USD 50 million in direct disruption, with a likely range of USD 20–100 million, concentrated in defense-grade operations, ultra-low-latency finance, and backbone telecommunications. We recommend publishing post-mortems with cost metrics to refine these estimates. Moving to a continuous UTC by or before 2035, as mandated by the 27th CGPM, would remove a brittle failure mode and reduce recurring coordination burdens across critical infrastructure [4–6, 18, 19].

Supported by the data on the cost and on the risks associated with the leap second, we think that the decision to cancel this procedure for one century or more is sound. Moreover, we are convinced that a time offset of a few minutes with respect to astronomical time would be hardly perceivable, as we already experience larger time shifts due to time zones: as an example, from October to March, time in Paris, by convention linked to the Central European Time (CET), is about 51 minutes later than its astronomical (solar) time.

Author Contributions

A.D.A.: conceptualization, methodology, supervision, reviewing and final draft editing; B.G.M.: bibliographic search, data curation, draft preparation. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used ChatGPT 5 Pro for the bibliographic search and for the first analysis; at the end, for a linguistic review of the final version. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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