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The Debate over UTC and Leap Seconds

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A recommendation pending before the study groups of the International Telecommunications Union – Radiocommunication Sector (ITU-R) would abolish leap seconds in Coordinated Universal Time (UTC). This would have significant near-term consequences to astrodynamics, astronomy, and other technical fields, and long-term societal and cultural implications. This paper invigorates the long standing leap-second debate with an open discussion of issues quietly considered for over a decade. It presents the pros and cons of the proposed change to UTC to those potentially affected by it. With the understanding that standards already accepted and implemented should be changed only in the most strongly justifiable circumstances, this paper recommends an approach that the authors feel meets technical, political, and operational needs.

I. Introduction

Timekeeping has always been based on cycles. A clear example is the alteration of night and day, a physical phenomenon that is everlasting, widely apparent, and countable, resulting with the solar day as the most fundamental cyclic unit of all calendars.[1] The usefulness of cyclic calendars led to our traditional reckoning of civil epochs as a calendar date, with some fraction of the calendar date being expressed as astronomical "time of day." Various other cyclic phenomena and physical processes were used to further parse the time of day into shorter and more uniform increments throughout history—the regulated flow of sand and water, pendulum swings, vibrating crystals, and atomic radiation.[2] During the 20th century, timekeeping became precise enough to discover that the Earth's rotation rate was not perfectly constant. This led to atomic resonators becoming the basis of the *Système International d'Unités* (*SI*) second, astronomical observations determining the rotation of the Earth, and the UTC time scale combining these phenomena into a uniform, worldwide standard for civil timekeeping well-matched to historical conventions.

A. Astronomical Time

Universal Time (UT1) is a precise measure of the Earth's terrestrial origin (prime meridian) about its observed rotational pole. Today UT1[*] is defined in terms of is relationship to the so-called Earth Rotation Angle, the angle of the Terrestrial Intermediate Origin (TIO) from the Celestial Intermediate Origin (CIO):[3]

$$q = 67310.54841001 + 86636.546949141027086\, T_u\,. \qquad (1)$$

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[*] "UT1" is the accurate label for Universal Time derived from Earth rotation, but "UT" is often used as a less precise general term (especially as mean solar time). This convention is followed here.

Here, T_u is the number of days of UT1 elapsed since Julian Date 2451545.0 UT1, q being determined mostly from observations of extragalactic radio sources using Very Long Baseline Interferometry (VLBI). Under this definition, the time derivative of UT1 is directly proportional to the rotation rate of Earth, which is unpredictably irregular to a few parts per one-hundred-millionths of the mean solar day. The constant of proportionality is traceable back to Newcomb's determination of the mean motion of the apparent Sun, thereby making UT1 a very close approximation to the mean diurnal motion of the Sun and the best indicator of astronomical time of day presently maintained.[4]

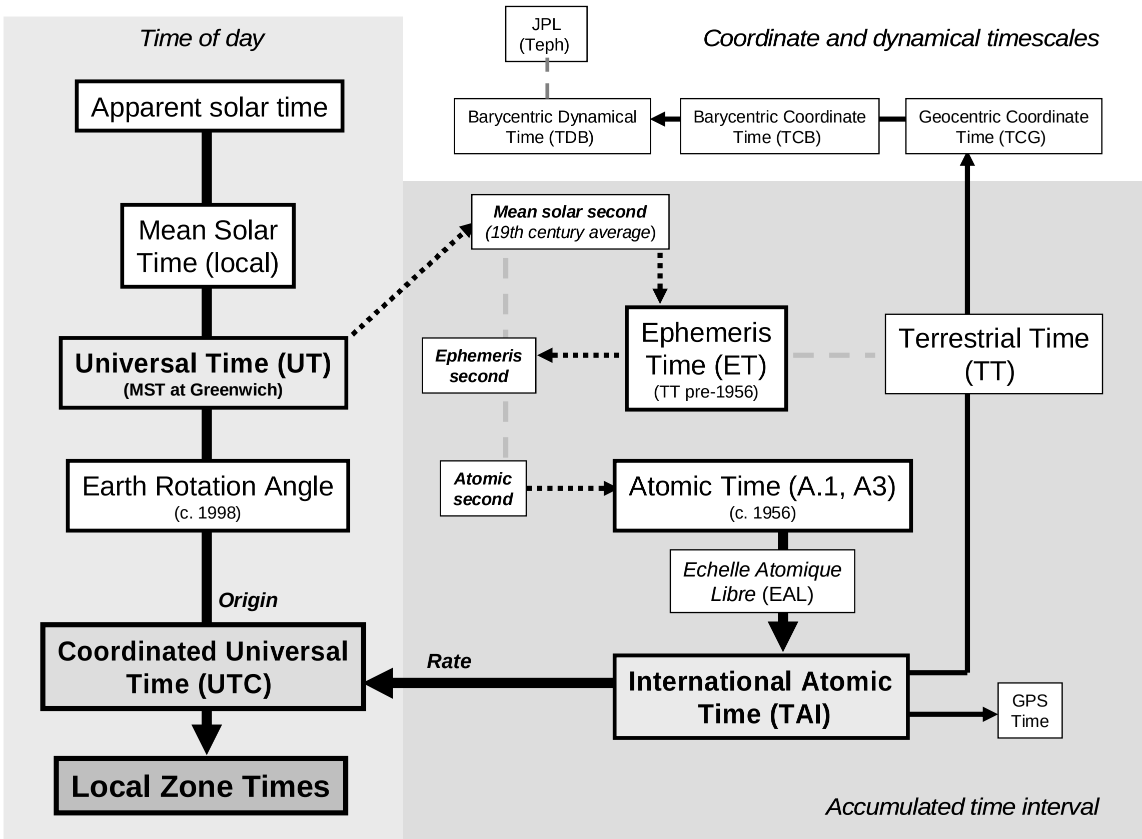

Figure 1. Relationships Between Time Scales.

B. Atomic Time

Newcomb suspected Earth rotation to be slightly irregular, due to the unpredictability of lunar ephemerides using his realization of mean solar time as the independent variable.[5] By 1960, Ephemeris Time (ET)—the independent variable of solar-system ephemerides—had become the basis of the *SI* second because of its theoretical uniformity. ET was realized by comparing more recent astronomical observations to a solar-system theory developed from observations from the latter 18th and 19th centuries (Figure 1).[6] In principle, ET-UT corrections would allow one to deduce a more uniform time relative to UT maintained by civil clocks; however, it took several years of celestial observations to accurately estimate ET-UT after the fact. In the 1950s, atomic resonators were also being developed to provide ultra-precise measures of time interval independent of astronomical phenomena. By 1958, 9192631770 periods of the radiation emitted from cæsium 133 was measured to be, within the uncertainty of astronomical observations, equivalent to the ET second.[7] By 1968, the definition of the *SI* second had been officially changed to the atomic frequency standard.[8]

International Atomic Time (TAI) formally began by averaging the readings of many national atomic standards.[2] It attempts to be a practical realization of a uniform time line based on an uninterrupted sequence of *SI* seconds near the surface of the Earth.* TAI is therefore a "paper clock"—a series of predictions and corrections to the readings of various national frequency standards published by the Bureau International des Poids et Measures (BIPM)† through *Circular T*.[9] New realizations of TAI are determined monthly as well as annually.

C. Coordinated Universal Time (UTC)

TAI provides a precise time scale for reference purposes, but for everyday purposes the world uses a system of civil time scales that correspond to the alternation of day and night. These time scales apply over wide areas and are easily related to each other as well as atomic frequency standards.[1] Prior to 1972, civil time scales and shortwave-radio timing signals maintained proximity to Universal Time through rate steering and steps of up to 0.1 s, owing to legislative and regulatory obligations that civil timekeeping reflect the astronomical time of day. But this caused the length of broadcast seconds‡ to be slightly variable and different than the *SI* second, which was inconvenient for the calibration of frequency oscillators from radio timing signals.

At a meeting of the CIPM in 1968, the concept of the leap second was proposed independently by Winkler and Essen as a more appealing means for synchronizing atomic frequency standards with astronomical time of day[10] Such a system allowed uniformly broadcast atomic seconds to be maintained on pre-existing mean-solar-time clocks (except during leap seconds). Adjustments of one second were small enough so as not to significantly impact the reckoning of civil timekeeping for everyday purposes or raise questions about UTC as a viable realization of astronomical time of day.

Although the new UTC system considered the accuracy needed for celestial navigation, leap seconds by themselves did not meet the accuracy needs of navigators, since deviations from UT1 greater than 0.2 s were unacceptable for navigation purposes.[11] Coded information was necessarily added into radio timing signals to allow for the recovery of UT1 to a precision of 0.1 s.§ Leap-seconds thereby made the frequency standard—the atomic second—available with UT1 in a single broadcast, UT1 being the recognized astronomical basis of civil timekeeping.[12]

Today, UTC can be realized through many different means to various levels of fidelity, including radio signals, the US Global Positioning System (GPS), communication- and weather-satellite broadcasts, Internet timing protocols, *etc*. Ultimately, the degree to which a user's frequency standard provides TAI-like time depends on the precise method of synchronization and the stability of the device in use.

II. The Application and Implementation of Time

Frequency standards permeate our lives. These rely on precision time intervals, not on the aggregation of elapsed time. They do not depend on the definition of UTC epochs or whether there are intercalary insertions, although they presently rely on UTC for disseminating the standard time interval continuously. The more narrow the bandwidth of the application, the more this matters. The more spectrum consumed by these applications, the more diligently spectrum is allocated, and the more narrow the bandwidth becomes.

Applications that depend on elapsed time from a user-defined epoch need not be affected by the definition of UTC. Examples include ranging—measuring the time of flight of a signal and energy returned from a distant object. The chosen epoch doesn't matter to the measurement. Asynchronous telecommunications are similar. Users can share a common epoch that can be established and reestablished collaboratively. GPS time is a widely available reference, although the GPS time intervals are not explicitly connected with astronomical events or fundamental frequency standards. Rather, GPS Time is "steered" to predictions of TAI (with the difference from UTC being a changing integer number of seconds). Therefore, except for the labeling of epochs, the UTC and GPS scales are synonymous to well below the microsecond. To a precision that matters to only a few applications, a "GPS second" is not a suitable frequency benchmark.

Many applications within a collaborating group may rely on the accumulation of time intervals elapsed from a universally common epoch. The epoch may be discretionary but widely held, such as continuous counting of seconds from a local epoch (atomic time scales at various laboratories). This category includes time scales tied to the rotation of the Earth, such as counting of astronomical days in order to maintain civil and religious calendars. Since

* Since the various contributing frequency standards are affected by their environs (temperature, gravitational field, *etc*.), the TAI second is only an approximation to the *SI* second.

† BIPM is constituted internationally for establishing time intervals and aggregated time. the International Earth Rotation and Reference System Service (IERS) is the international collaborative body responsible for determining and realizing time based on observations of Earth Orientation.

‡ These were sometimes described as "rubber" or "elastic" seconds.

§ The encoded difference of UT1-UTC is known as DUT1.

precise applications invoke both the definition of the standard time interval (*SI* second) and a common reference, they have required universal coordination.

Astrodynamics and astronomy depends particularly heavily on a precise definition of a standard time interval from a uniform epoch that should not be changed capriciously. A change to UTC will significantly impact some aspects of these fields.

III. The Issue

How we should synchronize astronomical time of day with atomic frequency standards is a matter of judgment, consensus, acceptance, standards, and implementation, with the results having important scientific, technological, legal, philosophical, and sociological implications. The need to balance public expectations for civil time based on historical, philosophical, religious, and technological prejudices was thoughtfully considered by the International Radio Consultative Committee (CCIR)[*] and the International Astronomical Union (IAU) when UTC was established, with the answer being UTC's system of leap seconds.[13] The adjustments afforded by leap seconds were necessary for three reasons:

(1) The duration of the TAI second is traceable to 18th and 19th century observations of mean solar time, and was thusly prescribed about 20 nanoseconds too short relative to the average mean solar day of the latter 20th century (Figure 1).

(2) Earth's short-term rotation advances and retards slightly relative to atomic standards in ways that are not predictable.

(3) The very long-term rotation rate of the Earth is decelerating very slowly due to tidal effects from the Sun and Moon, thereby increasing the length of the solar day very gradually (less than 2 ms per century).[14]

Because UTC with leap seconds was an atomic realization of Universal Time (or, if one prefers, mean-solar time), it satisfied the legal and regulatory requirements for astronomical time of day, and thereby became officially recognized for civil-clock usage by many national time-keeping authorities. The ITU-R became responsible for maintaining the definition of UTC through ITU-R Recommendation 460 because UTC originated as a standard for broadcasting radio timing signals in real time.[15] Over the years, the wording of Recommendation 460 has been slightly altered, yet with very little practical consequence on the administration of leap seconds.[†]

A. The Study Question

By late 1999, news came to the subscribers of IERS Earth-orientation parameters that a proposal existed "to change the definition of Coordinated Universal Time (UTC) regarding the insertion of leap-seconds, possibly even eliminating their use."[16] During the next year, the ITU-R Working Party WP7A drafted a new Study Question, ITU-R 236/7 (2001) asserting that "the occasional insertion of leap seconds into UTC creates serious difficulties for many operational navigation and telecommunication systems today," and asked that the following be studied:[17]

(1) What are the requirements for globally-accepted time scales for use both in navigation and telecommunications systems, and for civil time-keeping?

(2) What are the present and future requirements for the tolerance limit between UTC and UT1?

(3) Does the current leap second procedure satisfy user needs, or should an alternative procedure be developed?

To facilitate study of the Question, ITU-R 7A (WP7A) appointed a Special Rapporteur Group (SRG).[18] By its second meeting in Paris, March 2002, the SRG converged to the opinion of freezing the difference between UTC and TAI at the then-current value of 32 seconds, and decided that it would be necessary to retain the name "Coordinated Universal Time" and the abbreviation "UTC" to avoid potential problems regarding the definition of national time scales in countries where UTC was the legal basis.[19] At approximately the same time, several members of the SRG co-authored a comprehensive review and position paper which anticipated "a disassociation of civil time from solar time altogether," most likely by discontinuing leap seconds in UTC.[20]

B. The Answer: Leap Hours?

Fact-finding surveys were conducted by the IERS and URSI Commission J from 1999 to 2001, with the results suggesting that precision users of UTC were "overwhelmingly satisfied with the current method of determining

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[*] The CCIR became known as the ITU-R in 1992.

[†] Early changes extended the tolerance of DUT1 up to 0.9 seconds. More recently, 460-5 dropped language that had remarked "GMT may be regarded as the general equivalent of UT." Presently 460-6 recommends that radio-broadcast time signals provide DTAI (TAI-UTC) but lacks a specification for doing such.

UTC (leap seconds)."[21] [22] The SRG concluded that these surveys results "did not provide any clear resolution" and organized a special colloquium in Torino (Turin), Italy for May 2003 on ***The Future of UTC***.[18] The Colloquium press release noted that the SRG's work to date had "produced a consensual opinion" that the SRG wanted to present and discuss with interested and representative parties.[23] An invited presentation given by BIPM representatives subsequently proposed that leap seconds be halted and replaced with a "leap hour" to be inserted in about the year 2600.[24] This proposal effectively fixed the offset between UTC and TAI while also purportedly satisfying legal mandates to approximate mean solar time. Summer-time or daylight-saving-time legislation is sometimes pointed to as a precedent favoring wide legal leeway for strict solar timekeeping by intervals of up to one hour (although such a legal argument has limitations).[13]

The suitability of the leap-hour proposal as a proxy for mean solar time was debated at the Torino Colloquium, because a realization of UT1 to within one hour is not accurate enough for any practical purpose. On technical grounds, continuing the label "UTC" was considered potentially harmful and technically confusing for an atomic time scale no longer closely coordinated with UT. On philosophical grounds, it seemed highly presumptuous to codify an action now that might take place six centuries into the future. Attendees consequently drafted a single-page summary of finding to clarify the following consensus positions:[25]

(1) No recommendation to change UTC was reached.

(2) No alternative adjustments to leap seconds (particularly, leap hours) should be advanced "understanding that sudden or dramatic change to UTC was generally agreed as undesirable".*

(3) A civil standard not tied to Earth rotation would be fundamentally different from existing and historical practice, and should therefore omit any reference to "Universal Time" by title. "International Time" (TI) was therefore suggested as a replacement label for "UTC without leap seconds."

(4) Recommended changes—if any—should happen in the distant future to provide ample time for such a fundamental change to civil timekeeping (***e.g.***, a lead time of approximately two decades was suggested).

Despite objections, in October 2004 US delegates to the ITU-R WP7A quietly submitted a proposal to increase the permitted tolerance of the difference between UT1 and UTC to one hour, starting as soon as 2007. In July 2005, a notice was sent to IERS Bulletins C and D subscribers, citing November 2005 as possibly the last opportunity for input before a recommendation to redefine the UTC standard might be approved by WP7A.† This news triggered a July 29th article on the front page of the ***Wall Street Journal***.[26] Eventually the controversial leap-hour proposal lacked support within WP7A.

C. The December 2005 Leap Second

By 2005, "experts on both sides of the debate agreed" that there were "little data beyond a few anecdotes to suggest that leap seconds have created havoc in time-sensitive endeavors."[27] This dearth of evidence was expected to change with the introduction of a leap second in December 2005 following a seven-year lapse. According to the ***Washington Post***, the chairman of the SRG expected significant problems to happen, promising "If there are no significant problems, the whole issue will go away…"[27]

Considering that there had been a very large time interval since the last leap second, the number of problems experienced in 2005 was surprisingly low. In an annex to a 2006 report to WP7A, the SRG analyzed the 2005 leap second based on responses received by the ITU-R bureau and other responses and materials gathered directly.[28] The majority of responses were from timing centers reporting few if any problems with leap second implementation. The SRG also found that responses from companies and organizations generally reported little or no problem. Most of the reports were of problems with the Network Time Protocol (NTP) servers without much detail, which suggested a lack of uniformity in equipment systems in handling leap seconds. Other scattered issues were also reported, but none of them were identified as "significant" problems.

D. Recent Developments

A report of the SRG's multi-year study was finalized by 2008 without reaching a substantial conclusion regarding the original Study Question, and lacking in strong documentary evidence that would support a change to UTC. This lack of finding led to the rapid creation of a drafting group spearheaded by representatives of the BIPM, which wrote an expedient "final" findings report that leap seconds be suppressed on behalf of the ITU-R. This report concluded, in part, that the lack of responses by some major organizations so far on this subject, such as the American Astronomical Society (AAS) and the International Astronomical Union (IAU), indicated that these organizations were "completely or more or less neutral" regarding the proposal to redefine UTC.[29] However, the inability to sub-

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* http://www.ien.it/luc/cesio/itu/colloquium_report_info_paper.pdf

† http://www.ucolick.org/~sla/leapsecs/gambis.html

mit a unified response does not imply indifference. The AAS Leap Second Committee disbanded in 2008 because "there appeared to be no consensus" within the AAS on the issue of UTC redefinition.[30] A 2006 IAU report similarly indicated a lack of consensual agreement within the IAU to redefine UTC, with the IAU study group disbanding with the understanding that no imminent action by the ITU-R was to take place.[31]

In 2007, the US Congress finally accepted a recommendation from NIST to change the legal basis of civil timekeeping in the USA from "mean solar time at Greenwich," accepting "Coordinated Universal Time" as more technically accurate.[32] In late 2009, some letters representing various arms of the US government had also been drafted and circulated which supported UTC redefinition, but did not seem to fully recognize certain impacts to technical areas that may be important to government agencies.[*] The United States Naval Observatory (USNO) conducted a brief online poll in September 2008 on behalf of US Department of Defense (DoD), although there was no widely coordinated call for participation, especially for civilian and commercial entities.†

In October 2009, in an unusual administrative move, the International Chairman of the ITU-R WP7A study group advanced to the next higher level (SG7) a recommendation to redefine UTC by discontinuing leap seconds. This recommendation was not based on group consensus, and representatives from two countries objected to the recommendation. At the SG7 level, additional technical information is presently being sought before the SG7 considers it in October 2010. If SG7 decides to advance the revised recommendation, it will be put before the next Radiocommunications Assembly in 2012 for approval. If the recommendation is implemented, UTC could be redefined by 2018.

IV. Issues with Leap Seconds

Almost all issues with leap seconds can be traced to lack of awareness, misunderstandings, or indifference with the UTC specification. The problems manifest themselves in two areas: time labeling and/or time display, and clock synchronization.

A. Errors Displaying Leap Seconds

Almost all clocks are descendents of "generic clocks" originally intended to indicate astronomical time of day. The astronomical assumption of exactly 86400 seconds per day, therefore, dominates the manufacture and design of clock hardware and software, even after many decades of leap seconds. However, a true "UTC clock" is a specialized timekeeper that must be able to display a leap second and distinguish between UTC days which may be one second longer (or shorter) than other UTC days.[13] According to ITU-R Recommendation 460, the inserted leap second should be displayed as 23h 59m 60s, but legacy generic clocks cannot display a 61st second as "60". A lack of inexpensive hardware and clock circuitry to correctly label a leap second has resulted in a variety of imaginatively non-standard ways to represent UTC or zone time near a leap second, which may cause problems trying to synchronize computer clocks near leap seconds.

Unix-like computer operating systems are generally leap-second aware; even so, different operating kernels may handle an electronic leap-second announcement differently.[‡] A previously common response was to set back the system clock by exactly one second, a practice which can adversely affect applications (*e.g.*, databases) by misrepresenting the ordering of timed events. Other system clocks hold the same time stamp throughout the leap second, which avoids most of the drawbacks of time set-back but potentially creates duplicate time stamps.[§] A more modern practice is to temporarily slew the system clock frequency by a small percentage (such as can be done by the `adjtime()` system call of BDS Unix).[**] This practice better preserves monotonic clock output but results in less accurate time stamping in the minutes surrounding a leap second. Ideally, kernel time-conversion routines should show the leap second as number 60; routines that do this are compliant with ITU-R Recommendation 460.

One simple solution is to forgo any leap-second insertion and allow incorrect time labels until the system clock has been reset against a timing service. Computers are not accurate clocks, such that most are programmed to regularly reset the time against an accurate time source anyway. Because of this, it is straightforward to automatically reset the clock immediately following a leap second, but this practice can cause a surge of network traffic and place a heavy load on network-based time services.[33]

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[*] http://tycho.usno.navy.mil/Discontinuance_of_Leap_Second_Adjustments.pdf

[†] http://tycho.usno.navy.mil/leap_second_poll.html

[‡]http://www.meinberg.de/english/info/leap-second.htm#ntp

[§] http://www.eecis.udel.edu/~mills/leap.html

[**] The Windows operating system clock does not know about leap seconds. However, there are reportedly versions of the NTP daemon available that can quickly slew system time to account for the insertion of a leap second.

B. Errors Introducing Leap-Seconds

In many cases, time-processing components are capable of handling a leap-second, but the input of the leap second has been error prone. The problem has been compounded by the fact that leap-second notifications are not autonomously received by many timekeeping systems and must be entered manually.[34] The official means of distributing leap second announcements is done through the publication of IERS *Bulletin C*, mainly through email up to six months in advance.

The Network Time Protocol (NTP) has been in existence for decades and is a widely used method of time synchronization for network-connected computing devices. The latest version (4) of the protocol now supports leap-second notifications,[*] but it was not in use when the ITU-R Study Question was first raised. To facilitate the determination of time intervals spanning leap seconds in Unix-like systems, the exact times of leap-second insertions are kept in a system file obtainable via NIST and other sources.[†] Updates of this file can be made autonomously for most network-connected computers. This file may even be used to recover a form of real-time TAI from the operating system's realization of UTC.[35]

IRIG time codes may be used to transport time information between two physically-connected IRIG-compatible devices (*e.g.*, computers). The IRIG frame type IEEE1344 contains the necessary information that could properly display a leap second, but according to the specification, the leap second is only announced about a minute before it actually occurs. Such short notice generally precludes timely notification very far downstream in a network environment, resulting in irregular device notifications. Legacy IRIG frame types may also limit a system's ability to properly display a leap second.

Shortwave WWVB broadcasts include a leap-second indicator bit that can provide autonomous notifications of leap seconds of up to thirty (30) days in advance, although it seems that code is not widely used.

UTC parameters broadcast by GPS include the week and day-of-week number after which the leap second will be inserted, so the firmware of a GPS receiver can determine the date of leap second insertion in advance. Historically, the GPS system broadcasts notifications of leap seconds soon after their announcement via *Bulletin C*. GPS seems to be the most reliable method to date for obtaining reasonably accurate UTC and advanced leap-second notification in the absence of network connectivity.

C. Misunderstanding or Ignorance of the UTC standard

Though the use of UTC is pervasive, ITU-R Recommendation 460 is not in the public domain. Consequently, software designers and hardware manufacturers have not always been factually aware of its prescriptions, which has almost certainly led to past errors in implementation. As an example, according to ITU-R Recommendation 460, a single leap second may be added (or subtracted) to the end of any Gregorian calendar month given eight-week's notice. Yet it remains a common misconception, even among timekeeping authorities, that leap seconds may only occur at the end of June or December. This misconception appears to be a result of the traditional wording of IERS *Bulletin C* that announces leap seconds. Another common misconception that has been built into many systems is that leap seconds can only be positive; an example of this seems to be the unsigned leap-second indicator bit in the WWVB time code.[36] This misconception seems due to the fact that a negative leap second has never occurred, with experts acknowledging that it is unlikely to ever be necessary. Yet another misconception reflected in early POSIX standards was that more than one leap second could be inserted at a given time.

The practice of coercing generic clocks into displaying UTC has also resulted in the widespread misconception that the atomic UTC time scale lacks sequence or coherence, or, is "discontinuous." (An example is a computer-operating-system clock that halts for one second at 23:59:59 while a leap second is being added.) However, *UTC is completely sequential and coherent* within the prescriptions of ITU-R Recommendation 460. To clarify this point, consider that Julian dates progress continuously from a common prehistoric reference and are counted continuously since that epoch, but calendars (based on astronomical cycles) may label the same days in an irregular fashion. In neither representation are days "missing" and it is never suggested that a year is "discontinuous" at the insertion of February 29. Interpreting the passage of time with standards that have changed since inception is an interesting and sometimes involved book keeping task, but time itself and time scales are continuous. UTC is just as continuous as TAI.

There is another perception that the UTC time scale is not uniform, although it is rarely clarified that it is the length of the UTC *day* that is non-uniform. Every second of UTC is uniquely prescribed and (presumably) equal in duration to every other second, such that its progression of seconds still qualifies as a uniform time scale. For most precise applications, UTC is just as uniform as TAI.

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[*] http://tools.ietf.org/html/rfc5905

[†] ftp://time-b.nist.gov/pub/leap-seconds.list

V. The Debate

The question of redefining UTC has been with us for more than a decade. The debate is far from being as simple as whether to "just stop leap seconds." The current definition is transparently and irrevocably built into many advanced functional systems. Astronautical, astronomical, and navigational applications especially use UTC as a direct realization of Universal Time where one-second accuracy is sufficient (or 0.1 second accuracy can be achieved with DUT1). The notion of just switching to "a different time scale" is also complicated by the fact that there are legal mandates and public expectations to maintain something called "UTC", these originally supposing that UTC was a realization of astronomical time of day.

Arguments for and against the abolition of leap seconds have been reported through several reports and articles, with varying degrees of detail and perspective. A detailed presentation of the advantages and disadvantages to the many users of UTC will be needed to discuss the issues candidly and make important decisions. Table 1 in the appendix compactly summarizes some of the pros and cons of changing UTC from the perspectives of various stakeholders and their potentially affected applications, and the following sections outline some of the major points of the debate and the detailed arguments behind them.

A. Need for a Continuous / Uniform Standard Time Scale

1. Communication systems.

Favoring change: Spread-spectrum systems rely on time synchronization for effective communications. When synchronization is lost, so too is coherent communication. Thus, while a leap second is being introduced, and until synchronization is established, communications can be disrupted between some systems.[37] For example, a 2008 *New Scientist* article reported that cellular-phone communications "blacked out" over part of the southern US when the December 1998 leap second caused different regions of service to slip into slightly different times and temporarily prevented the proper relaying of signals.[38]

Opposing change: The occurrence of a leap second should not cause loss of coherent communication if the system conforms to ITU-R Recommendation 460. Many descriptions of leap seconds problems, such as the report of a regional cellular-phone-system outage, occurred so long ago that they cannot be easily confirmed or denied; even so, there is no reason to believe that the problem still exists or would be replicated now or the future. The underlying premise should be that any communication network that experiences problems with leap seconds will work to fix, rather than continue with, faulty methods once discovered. Where systems can cope with synchronization lost for reasons other than leap seconds, then those mitigations strategies should also apply to rare leap second events. Also, only communication systems that depend specifically on time epochs may be affected by the introduction of leap seconds; systems depending on frequency have little or no sensitivity to epoch.[20]

2. Telecommunications, Navigation and Related Fields.

Favoring change: Recent advances in telecommunications, navigation and related fields are moving toward the need for, or will require, a single, internationally recognized uniform time scale that is widely available.[17] [20] Deleting the leap second could allow UTC to be this uniform time scale in the future.[39]

Opposing change: UTC is uniform in its progression of seconds of equal-length and thereby qualifies as a uniform time scale, since the non-uniformity of UTC is in the length of the UTC day. There is nothing inherent to recent advances in telecommunications, navigation, and related fields that require calendar days to have equal atomic duration. Also, the elimination of future leap seconds from UTC would not necessarily diminish the use of, or need for, pre-existing times scales already used by some communication systems. For example, some networks are based on GPS time, including cellular phone networks.

3. Predictable Time Tags Long-Term.

Favoring change: There are specialized technical applications, such as long-term forecasting and mission planning, which may require the forecasting of events to better than one (1) second more than six months in advance. Examples include spacecraft missions and astronomical / astrodynamical ephemerides. The insertion of a leap second into a predicted timeline requires the regeneration of the mission schedule or ephemeris. This results in multiple versions of the predicted timeline, and raises questions about which predictions are aware of the upcoming leap second.

Opposing change: These applications are not particularly bound to the region of the Earth's surface and, therefore, have their own time scales. The elimination of future leap seconds from UTC would not diminish the need for these coordinate and dynamical time scales (Figure 1). At one point the ITU-R recommended the possibility of using TAI-like time in lieu of UTC (via Recommendation 485, now withdrawn). Compared to the duration of a single leap second, the difference between UTC and TAI labels is now sizable, which could minimize confusion between them. In cases where UTC is used for long-term scheduling regardless, predicted events (say, a spacecraft maneuver or limb occultation) forecast more than six-months in advance will have an uncertainty larger than one second, and schedules would be updated regardless of leap-second occurrences.

B. Safety Concerns

1. Launch activities.

Favoring change: Leap seconds may adversely influence the scheduling of NASA and ARIANE rocket launches.[28 29] It has even been asserted that ESA does not launch during months with leap seconds.[40]

Opposing change: Since leap seconds are relatively rare events, and since approximately two-thirds of all leap seconds already coincide with a world-wide national holiday, the actual impact of leap seconds on launch activities must be very low. If launch avoidance policies exist, they may simply be precautionary rather than out of necessity. Unfortunately there is a lack of publicly available information that confirms or denies claims that launch schedules intentionally avoid leap seconds as a matter of administrative policy. However, the claim that ESA does not launch during months with leap seconds has been refuted by an ESA official.[41] It is also easily verified according to ESA's own launch schedules.[*]

2. Navigation interruptions.

Favoring change: GLONASS system time is referenced to UTC + 3 hours (Moscow Time), such that its satellite clocks account for leap seconds. During the introduction of a leap second, the clocks are not synchronized and the system becomes unavailable for navigation service. In 1997, GLONASS was broken for 20 hours after a transmission to the country's satellites to add a leap second went awry.[26 42 43] If worldwide reliance on satellite navigation for air transportation increases in the future, depending on a system that may not be operational during some critical areas of flight could be a difficulty.[37]

Opposing change: Brief interruptions and performance degradations are to be anticipated from electronic navigation aids, even during critical areas of flight. Mitigation strategies exist in such cases and these strategies would apply to rare leap-second issues if they should happen. GPS navigation is not usually affected by leap seconds, and the Galileo system plans to align its system time with GPS. And while past GLONASS performance has suffered due to leap seconds, the performance problems are documented to be minor.[44] The GLONASS leap-second issue has been described as an interruption of the GLONASS navigation message, each line of the message starting with every *even* second and lasting up to two seconds.[45] Obviously the introduction of an odd leap second could interrupt this cadence; if so, the GLONASS navigation issue is not really about a deficiency in the existing UTC standard, but a specific limitation originally written into the GLONASS ICD. Recognizing this problem, GLONASS developers planned to significantly reduce outages with the next generation of satellites.[37] Ultimately, GLONASS representatives submitted a written statement dated May 13, 2003 (in Russian) to the proceedings of the Torino Colloquium, requesting that status-quo UTC be preserved to avoid further changes to the GLONASS navigation messages, changes to the logic of GLONASS system operation, and adjustments to GLONASS service documentation.[42] Finally, the 1997 GLONASS outage was "not connected with leap second correction;" the referenced outage had been scheduled in advance to tune the frequency the GLONASS Central Synchronizer clocks to stabilize the difference between GLONASS system time and UTC(SU).[45 46]

3. Time scale confusion.

Favoring change: Modern commercial transport systems depend almost entirely on satellite navigation systems. Future systems are likely to rely on these systems and their augmentation systems to improve navigation accuracy, reliability, integrity and availability beyond current capabilities. Increasing worldwide reliance on satellite navigation for air transport is likely to demand systems free of any unpredictable changes in epoch.[20] Mistakes in timekeeping could lead to flight accidents "and they could be a danger."[43]

Opposing change: The offset between UTC and GPS time is broadcast by the system such that receivers can report out UTC or local zone time. The availability of both GPS time and UTC offsets has not been a critical design issue for navigation hardware in general, so it seems implausible that there should be confusion for air-traffic control in particular. Furthermore, where there is such confusion, it is unclear how the abolition of leap seconds remedies it.[†] Presently, there is a lack of evidence identifying leap-second issues that might be credibly described as "dangerous." Public debate over leap seconds has ensued for at least a decade, and all serious proposals to eliminate them would put the demise of leap seconds well into the future. If *status-quo* UTC were truly a menace to safety, its abolition would have come swiftly and decisively.

[*] http://www.esa.int/SPECIALS/Launchers_Home/

[†] A recent example is the display of zone times relative to GPS time instead of UTC in some DROID™ cellular telephones. This is not a leap second problem; leap seconds actually help make time-scale confusion more obvious.

4. System incompatibilities.

Favoring change: In global synchronization operations involving multiple locations, one frequently deals with differing hardware and software systems based on different standards and operating practices. The possible introduction of one or two 61 s minutes per year into continuous site processes would directly affect synchronization, if the leap seconds were not treated identically at the same instant at all cooperating sites.[20]

Opposing change: The existing UTC standard already promotes identical treatment of all leap seconds; therefore, this concern is not really about a particular deficiency with the existing UTC standard, but conjecture about the repercussions of improper, non-standard implementations. Implementation mistakes are entirely possible ***without*** the existence of leap seconds, and timekeeping problems of this type may continue regardless of how UTC is defined.

5. Proliferation of "pseudo time scales."

Favoring change: The possibility of time-service disruptions to modern data systems would have a major impact on their interactive operation. In some cases, the need to avoid disruptions has led to non-traditional timekeeping systems, such as GPS Time or a time scale maintained by an individual government contractor. Continuing use of a non-uniform time scale including leap seconds could lead to the proliferation of nonstandard time scales that are more suited to their individual requirements. If that happens, UTC would be less accepted as an international standard.[20] [37] This multiplicity of "pseudo time scales" could lead to confusion and potentially disastrous consequences.[47]

Opposing change: If the existing UTC standard unduly promotes the proliferation of time scales without leap seconds, how does the creation of ***yet another*** time scale without leap seconds provide for an equitable solution?[13] Since leap seconds already exist in the historical record, the abolition of future leap seconds does not eliminate the burden of applications needing to responsibly handle historic leap seconds. Rather, the situation would be greatly complicated by the existence of two fundamentally different atomic scales called UTC (one with leap seconds in the past, and one without) and it would become more difficult to convolve observations made in the past with future observations. Apart from GPS time, which is widely exposed, there seems to be a lack of evidence of widespread adoption of alternative time scales. Some scales exist, not to avoid leap seconds, but are different than UTC for security reasons and this will not change should UTC discontinue leap seconds. The creation of yet another atomic time scale without leap seconds is simply unneeded.

6. Increased operational risks.

Favoring change: The real-world operation of timing systems is confronted by equipment upgrades and personnel changes. The possible effects of maintenance procedures and human factors in accommodating leap second steps should be given consideration in assessing the reliability of such systems.[20]

Opposing change: UTC has been almost universally adopted as an operational standard, and it has remained largely unchanged after four decades; this suggests many applications function adequately in the presence of leap seconds. History has proven that the consequences of leap-second issues are rather minor, easily noticed in precision applications, and quickly resolved compared to many of the other issues that can effect real-world timing systems, such as equipment failure. Procedural concerns, including issues due to leap seconds, can be reduced or eliminated with ongoing personnel training and improved system automation.

C. Clocks and Time Representation / Registration

1. Problems representing a 61st second.

Favoring change: In today's world of high-speed inter-computer communications that time-stamp messages at the sub-second level, 1 s can be a significant length of time. Many computer systems and precise clocks have a problem introducing the second labeled "60", leading to, among other things, problems with time stamping legal documents.[20]

Opposing change: Computing equipment is relatively low cost and rapidly replaced in today's world. Time-representation issues are usually limitations within computer operating systems which are inherently extensible and upgradable. The future of civil timekeeping should not hinge on the limitations of computer operating systems and software that are quickly outmoded (sometimes being replaced faster than leap seconds occur). Many computer operating systems network protocols now offer enhanced leap second notification and display, and it is reasonable to expect that this situation will only improve with time. Also, the requirement for sub-second time stamping of legal documents is uncertain.

2. Problems representing decimal fractions of a day.

Favoring change: When dating events using the Julian Day (JD) or Modified Julian Day (MJD) including fractions of a day, a positive leap second can create a situation where two events 1 s apart can receive identical dates when those dates are expressed with a numerical precision equivalent to 1 s.[20] [48]

Opposing change: The possibility of identical dates is largely academic, because applications that utilize fractional (M)JD are generally astronomical in nature and refer to scales without leap seconds, such as UT1, TT, *etc*.[13] The issue can also be remedied if fractional representations consider UTC days that are not strictly 86400 seconds of duration. That is, if 00h 14m 24s represents the first 864 seconds of the UTC day, then the fractional representation is 864/86400 = 0.01 for a UTC day lacking a leap second, and 864/86401 = 0.0099998843 for a UTC day with a positive leap second.

3. Universal "Time" really isn't.

Favoring change: Although UT1 is expressed as a time, it is not used practically as a time scale.[17] It does not truly represent time as defined today because it is actually an angle.[49]

Opposing change: Earth-rotation angle provides a sequentially increasing continuum that is everlasting and widely apparent, and its rate of uniformity is far superior to most mass-produced clocks and computers in use today. Also, whereas each revolution of the Earth is identifiable, individual atomic transitions are not; thus the one is truly a measure of time, the other of time-interval.[50] The suggestion that a rotating angle cannot represent time also suggests that a conventional (analog) clock cannot represent time, because analog clocks represent time with angles.

D. Costs of Changing

1. Software and hardware changes.

Opposing change: Leap seconds are now an established part of timekeeping procedures for technical applications. Custom and commercial equipment that already accommodates leap seconds would be obsolete. It may be difficult or expensive to change time-transmission formats due to the prevalence of legacy hardware. Current formats depend on the fact that DUT1 is less than one second, and devices might be affected adversely by a change in the broadcast format.[39] Fixing, testing and documenting computer codes could be an enormous task.[20] The cost of revising software for data reduction, instrument control, and spacecraft operation is unknown, but initial estimates indicate that retrofit costs could be prohibitive for some (and might even lead to unsafe conditions). There may be unintended hidden costs of retrofitting numerous applications which assume UT1 is approximated by UTC.[39] This includes astronomical and astronautical applications which may not be aware of the difference between UT1 and UTC, or assume that the difference is always small.[39]

Favoring change: Before each leap second is applied, software and technical equipment undergo testing to ensure that systems will behave as expected before, during, and after the leap second. The cost of that testing is often hidden, but it cannot be ignored.[51]

2. Impact studies and preliminary cost estimates.

Opposing change: Highly reliable and/or official cost-estimates are often expensive to generate and approve.[52] Accurately responding to impact studies can be cost prohibitive as it sometimes requires cost-estimation resources and atypical knowledge regarding the way UTC may or may not be implemented within complex electronic systems. Even systems requiring no change still need to be very thoroughly assessed at moderate expense to determine this for a fact. Impact studies and cost-estimation analyses present unnecessary expenses to government, industry, and academia that could be used to address non-standard implementation issues with the current UTC definition.

Favoring change: Government agencies favoring the change are likely to subsidize cost-estimation efforts where needed. Impact studies might show that these applications could benefit from upgrades that allow UT1-UTC to be used explicitly. If the date of adoption is pushed out far enough, the expense can be absorbed into the total life cycle of systems being replaced or upgraded. Preliminary costs estimates to change some systems also seem unrealistically large.

3. No suitably convenient replacement.

Opposing change: For many systems, it is possible to obtain a sufficient realization of UT through the system's UTC clock, or some "UTC receiver" (such as GPS or WWVB) without any conscious effort on the part of their operators. There is no current replacement for the passive reception and easy availability of UT1 via UTC clocks and UTC time signals for applications that require it.

Favoring change: The IERS publishes tables of UT1-UTC via Internet resources. Internet availability is becoming more and more ubiquitous. There have also been suggestions that the ITU-R invite global navigation satellite systems (GNSS) to broadcast UT1-UTC in the future.

4. Increased Frequency of Leap Seconds.

Favoring change: Increasing frequency of leap seconds will be difficult to accommodate, and problems will only worsen when multiple leap seconds per year will be required due to tidal friction and decade fluctuations.[49] We may need to insert two leap-seconds per year this century.[39] UTC as presently defined cannot be sustained, since the long-term growth projection is expected to be quadratic, leading to the abandonment of the current UTC standard sooner or later.

Opposing change: Since the current UTC system already allows up to twelve (12) leap seconds per year, and since two leap seconds have already occurred in the same calendar year (1972), concerns about having two leap seconds per annum seem unjustified. Sophisticated timekeeping networks will have greater incentive to fully comply with the existing UTC standard if the frequency of leap seconds increases, so problems may be expected to diminish with time, rather than increase. Also, some users complain that leap seconds occur too ***infrequently*** to effectively test, such that some applications would actually benefit from more frequent leap seconds. Finally, by the time the standard needs to change because of more than twelve (12) leap seconds per year (this would be very many centuries into the future), probably other changes to the definition of UTC will have been implemented due to improvements in accuracy and availability.

5. Keeping the label "UTC".

Opposing change: Continuing a time scale called "Coordinated Universal Time" that is no longer coordinated with Universal Time will remain legally and technically confusing. There has been strong support for changing the name from UTC if the definition is changed, to make the differences clear.[39] Vast changes to the existing scientific and technical literature base will be required if UTC is redefined, so that would provide a convenient opportunity to operationally retire the name and clarify the fundamental extent of the change.

Favoring change: Changing the name is not recommended because "UTC" is the only time scale authorized for maintaining and distributing time.[47] This label is incorporated into the legal codes of many countries, so a change of name may complicate regulatory and legal acceptance, and could cause great confusion and complications in the ITU-R standards process. Timing signals before the introduction of leap seconds were also called UTC, so there is already some precedent for altering UTC without changing its name.

E. User Responses

1. Opportunities for input.

Opposing change: The majority of UTC users has not had the opportunity to voice opinions. Constituencies most affected are not directly involved, and responses have not been sufficient for sound inference of outcomes. Many applications potentially affected by the UTC redefinition do not currently rely on Earth orientation parameters or leap-second insertion, and their operators may be unaware of the usual services, circulars, or announcements regarding leap seconds and/or Earth orientation, or how their systems may be impacted. Therefore, the number of those adversely affected by the redefinition may be quite large, since surveys and queries about this matter have been generally limited to groups familiar with precision timing.[52]

Favoring change: Several surveys have been conducted by various organizations with an interest in precision timekeeping (URSI, IERS, CRL, American Astronomical Society, USNO, *etc.*). By 2008, the ITU-R process had received or generated over 40 documents, including expert position papers, both for and against.[29] Leap second issues have been mentioned at many technical meetings and conferences, including ION, PTTI, CGSIC, AIAA, *etc.* At least one electronic list service exists to openly discuss leap-second issues,[*] and public discussions are held in other electronic venues.

2. Outcomes of user surveys.

Opposing change: Past surveys have suggested that precision users of UTC are "overwhelmingly satisfied with the current method of determining UTC (leap seconds)."[21 22]

Favoring change: Surveys showing favor with the *status quo* are not necessarily a complete or scientific sampling. A sizable minority still expresses some dissatisfaction. In one case, a survey appeared to swing from being against change to favoring change after the scope of the survey was expanded.[29] Also, it is human nature to withhold the reporting of problems, so problems caused by leap seconds are likely to be underreported. There is no actual clearinghouse or repository for which to report problems related to leap seconds.

3. Professional indifference.

Favoring change: There are major organizations that have not yet publicly weighed in on this subject. Their lack of response could be interpreted as a neutral position.[29]

Opposing change: The inability to submit a unified response does not imply neutrality, and whenever opinions are strongly divided on such matters, it is usually understood by all parties that the *status quo* will maintain its privileged position, being the default standard. Therefore, a withholding of opinion implies favor for the *status quo*. After a decade of discussions, many people and organizations may have also become skeptical that the change will take place, or that their opinions matter, so they may no longer spend time considering the issue.

[*] http://six.pairlist.net/mailman/listinfo/leapsecs

F. Requirements to Track Solar Time

1. Celestial navigation no longer an issue.

Favoring change: The primary reason for leap seconds was to meet the requirement of celestial navigation.[20] However, the motivation for the leap second has diminished because of the wide availability of GNSS, and since sailors don't navigate with the stars any longer.[49]

Opposing change: While reliance on celestial navigation has greatly diminished with the advent of GNSS, the generalization that celestial navigation is no longer actively practiced is unfounded. Electronic navigation aids are subject breakdown and jamming, such that the US armed forces still teach navigation without GNSS and other electronic aids. Because LORAN is being phased out in the USA, celestial navigation is still used as a backup to GNSS, especially where military requirements mandate some kind of navigational backup at sea. Many professional sailors and civilian merchant marines also rely on celestial navigation as a back-up to GNSS, evidenced by the availability of private instruction on celestial navigation and the continuing production of sextants, nautical almanacs, and celestial-navigation textbooks. Also, the concept of the leap second was not introduced "to meet the requirement of celestial navigation" since that requirement was being met previously by timing-signal broadcasts without leap seconds. Rather, the UTC system with leap seconds was motivated to convenience the calibration of frequency while still satisfying legislative and regulatory obligations to keep timing signals synchronized with astronomical time of day. Celestial navigation further motivated DUT1 encoding within time signals.

2. Legal Concerns.

Opposing change: The decision is not just a matter of organizational declaration; laws and regulations will need to be changed because the legal basis of timekeeping is mean solar time or the equivalent in several countries. In other countries where UTC is the explicit legal basis, there may be political obstacles or questions about changing UTC. The very title "Coordinated Universal Time" expresses the requirement to track Earth rotation: nations adopting UTC broadcasts as their statutory or regulatory standard understood UTC to be a realization of Universal Time in title and purpose upon official adoption, and the obligation to keep pace with Earth rotation has never been repealed.[53]

Favoring change: If a change were adopted, it would represent a majority decision of participating nations within the ITU-R.

3. Large solar variances already tolerated.

Favoring change: Common practice today has already compromised the requirement to keep solar time to the point that societies are content with conventional constructions such as mean solar time, zone time and Daylight Saving Time.[20]

Opposing change: That some jurisdictions presently allow local clocks to vary largely from solar time is not a compelling reason to totally break from a solar-timekeeping standard. The practices of zone time and daylight savings (Summer Time) are relatively recent within the total history of civil timekeeping, but civil timekeeping with Earth rotation is longstanding. The existence of time zones actually suggests that people prefer to set their clocks to something that correlates with the Sun, and in regions of lower latitude where duration of daylight is less variable, Summer Time adjustments are neither desirable nor practical.[54]

G. Societal Implications

1. Historical continuity.

Favoring change: Keeping UTC tightly coupled to Earth rotation for cultural reasons is no longer compelling. Calendars have evolved for the benefit of society, and timekeeping methods reflect the technology of their day.

Opposing change: Humanity has always regulated its activities in concert with celestial phenomena. This is the most enduring practice and cannot be ignored. Civil timekeeping based on the rotation of the Earth relative to the Sun goes back to ancient times: UT is the embodiment of that fact. Leap seconds provide for a close connection between UTC and a time scale related to the Earth's rotation.[39] UTC is the enduring mechanism for correlating diverse time scales.

2. Societal problems.

Favoring change: It is unlikely that the growing difference between clock time and levels of daylight would be noticeable for the foreseeable future. Also, certain religious customs depend on the actual observation of the Sun or the Moon rather than clock time. Therefore, the elimination of leap seconds should have no practical effect on the correspondence between civil time and solar time or on contemporary social conventions.[20]

Opposing change: Civil calendars are inherently astronomical, and the solar day is the basic unit of the calendar. Because celestial phenomena viewed from the Earth are not in consonance with the rotation of the Earth or its orbital period around the Sun, civil timekeeping must accommodate days of variable length. Without leap seconds, a large correction will be required to correlate clocks back with the solar day. The societal problem of introducing a fractional day back into the calendar is historically unprecedented and will be an expensive and difficult proposition for the generation that decides to tackle it. Posterity might reintroduce leap seconds after several centuries to gradually reintroduce missing minutes back into the calendar.[13] Therefore, abandoning leap seconds does not offer any long-term improvement for civil timekeeping. In the short term, it raises many complicated philosophical questions that have yet to be thoughtfully posed and discussed regarding our preferences for solar timekeeping.

VI. The Standards Environment

From the British Standards Institution:*

> A standard is an agreed, repeatable way of doing something. It is a published document that contains a technical specification or other precise criteria designed to be used consistently as a rule, guideline, or definition. Standards help to make life simpler and to increase the reliability and the effectiveness of many goods and services we use. Standards are created by bringing together the experience and expertise of all interested parties such as the producers, sellers, buyers, users and regulators of a particular material, product, process or service.

There are two fundamental questions with respect to standards. “What is the role of the standards community in this area?” “What can the standards community contribute to resolving this matter?” To address the first question, this area is well within the responsibilities of the standards community. Standards establish the environment for collaboration and communication. They are demand driven in response to needs. They must honor heritage implementations. They are pursued by stakeholder experts. Development must be balanced, including academic, industrial, and governmental contributions.

There are two excellent, relevant examples. ISO Standard 8601 deals with approaches to representing time numerically. ISO/CCSDS 502.0-B-2, *Orbit Data Messages*, requires time-system and interval data and metadata.† Both were developed with balance among user and developer interests. True international standards will enable interoperable commercial and research equipment that serve the PTTI community.

The ability to deal with and manage change is one of the many ways that the standards enterprise can add value to addressing UTC. Only the most extreme anomalies justify changing an existing standard materially. For example, if the standard governing screw threads were changed, bolts would no longer fit existing nuts. Significantly changing the duration of the second is unthinkable. Imagine changing the definition of the meter‡.

We put changing the definition of UTC in the same category. Modifying a practice in place for years would confuse the community that is already deprived. We would at least have to amend the existing practice to accommodate UTC with leap seconds and UTC after leap seconds. Severing the relationship between useful time and atomic time would surely complicate scheduling collaborative operations. ISO 8601 will inevitably have to be modified. UTC is established as the standard for time data exchange both in wide practice and in some cases through statute. We must have an enduring scheme for translating from UTC to other more technically consistent schemes. This is a responsibility of the standards community.

Is the ITU-R still the right organization to define UTC? The concerns over the UTC time scale have little to do with radio transmissions now. Institutionalized international standards directives require that the decision making body be composed only of affected parties with a material stake in the matter, that there be balance within the decision making body (one affected constituency cannot dominate the decision), and that there be a minimum plurality or majority (a few votes for or against out of many that could be cast is not sufficient).[55] [56] UTC recommendations currently tabled do not meet these criteria. The standards community is experienced at gaining consensus among stakeholders with diverse motivation. This may be an important contribution.

Competent practitioners will be able to accommodate any of the mitigations suggested. This is an issue of practice and implementation effectiveness, which is the venue for standards. The International Standards Organization can guide a cohesive consensus that includes industry and government in addition to competent practitioners, not unlike a similar initiative proposed for the International Terrestrial Reference System (ITRS).[57]

VII. A Proposed Approach

The ITU-R has been entertaining proposals to redefine UTC for about a decade. It seems that the ITU-R has not formally petitioned affected scientific organizations for official responses. Outside this paper there has been little

* http://www.bsigroup.com/en/Standards-and-Publications/About-standards/What-is-a-standard/

† http://public.ccsds.org/publications/archive/502x0b2.pdf

‡ In fact, time and distance standards are not independent. The meter is defined as the distance light would travel in a standard time interval. Changing the definition of the second would implicitly change the definition of the meter to a degree that would affect astronomy.

organized discussion publicizing the significant number of pros and cons of the many users who would be affected by the present proposal to change UTC. There also remains the question of why the redefinition of UTC should reside with the ITU-R when radio transmissions of time signals are not a critical consideration. Hence, the following procedure is proposed if a redefinition of UTC is to be considered further:

(1) There needs to be a collaborative summary of the pros and cons concerning changing the definition of UTC. A summary is started in this paper for consideration by all those users affected by the change.

(2) Organizational responsibility for the definition of UTC should be reconsidered. There should be a formal consultation by the responsible organization with all the other organizations affected by the definition of UTC. Specifically, the IAU, IUGG, standards committees, UN committees, and other such organizations should be formally requested to provide written positions concerning the definition of UTC.

(3) There should be formal consultation with all nations concerning the possible effects on their legal time.

(4) If a redefinition of UTC is proposed that does not track Universal Time to within ±0.9 s, a new name for the new time scale should be adopted to avoid technical confusion in the future.

(5) Only after a unanimous consent is achieved should a change be proposed, and then the change should be introduced at least five (5) years after the announcement of the agreed-upon change.

(6) Availability of the new standard should not be encumbered by fees or concerns of copyright infringement.

VIII. Conclusion

A. Some Answers to the Original ITU-R Study Questions

What are the requirements for globally-accepted time scales for use both in navigation and telecommunications systems, and for civil time-keeping? UTC is an atomic realization of UT in title and practice, which is, in turn, the modern-day complement of mean solar time. Because atomic time has a rate different than mean solar time, the atomic realization of solar time must be adjusted; for UTC this adjustment is made to the length of the “UTC day,” the day being a non-***SI*** base unit. With regard to leap seconds, they exist because of legal mandates, technical requirements, historical precedents, and societal preferences for civil time-keeping, based on philosophical, sociological, and technological prejudices. Astronomical (mean solar) time undoubtedly serves as the basis of the civil calendar and civil time of day, such that some citizens expect a suitable measure of astronomical time directly from the basis of civil clocks.

What are the present requirements for the tolerance limit between UTC and UT1? Applications deriving astronomical time from civil clocks drive the present and future requirements for the tolerance limit between UTC and UT1. The discrepancy between UT1 and UTC has been purposely maintained within ±0.9 seconds, a tolerance which appears to satisfy most statutory and technical requirements for civil time scales having no significant secular deviation relative to the mean solar day at Greenwich, as stipulated under law by most nations (now or historically), and a tolerance that is now anticipated by the technical communities today.

What are the future requirements for the tolerance limit between UTC and UT1? Without ample economic and technical resources to evaluate and retrofit all systems now reliant on the existing UTC standard, the future requirement for the tolerance between UTC and UT1 also appears to be ±0.9 seconds. Allowable deviations larger than this have no known precedent in modern times and do not appear to have been tested. This tolerance has been tightly integrated into many operational systems during the previous four decades, and the need to account for leap seconds from the past will remain even if future leap seconds are stopped. If the tolerance were to change, the extent of adverse operational impact is unclear and it is also unclear where to adequately establish a new threshold.

Does the current leap second procedure satisfy user needs, or should an alternative procedure be developed? This paper presents the factual rationale that the existing UTC standard is valuable and that a consensus alternative is lacking given the current lack of consequential issues with the current standard, and given that the majority of precision users queried are satisfied with the current system. Many systems have specific operating assumptions and approximations designed around the fact that DUT1 is bounded at ±0.9 seconds, and the proposed change to UTC will affect applications that cannot yet handle an ever-growing difference between UT1 and UTC. Having such a tolerance mitigates specific technical risks now and in the future; specifically, the conventional proximity of UTC relative to UT1 acts as a safeguard (should Earth-orientation parameters ever become unavailable to a system, should a system operator make a gross error entering DUT1 , *etc.*)

B. Summary

The recommendations currently before ITU-R SG7 would alter the definitions of currently accepted standards and create additional standards, deprecating the installed base and future marketability of hardware and software that suits the purpose well. Consideration of the pros and cons indicates that eliminating leap seconds will serve to complicate astronomy, astrodynamics, and other sciences, rather than simplify. Meanwhile, the observed benefits to other users seem unremarkable. Other time scales and references will always be required, and transitions will be required among them. For decades, applications with very stringent requirements for timing accuracy (including GPS) have operated successfully despite the presence of leap seconds in UTC. Most applications that are noncompliant with UTC came into existence well after the UTC standard had been created. Reported problems seem to be minor and far flung, raising questions about claims that the current definition of UTC now posed a significant technological risk to an increasingly network-connected world. Study groups have not been able to show overwhelming deficiencies with the current standard after years of investigation. There is no evidence to suggest that today's technological inconveniences due to leap seconds cannot be overcome relatively easily and inexpensively as *status-quo* UTC is maintained into the future, and problematic technologies, where they exist, will necessarily adapt to the *status quo* if the definition of UTC is left unchanged. This may already be happening: the original question was raised based on issues that are now over a decade old, and the problems with leap seconds seems to have decreased in seriousness and frequency.

Any scheme other than that already in place will gradually diverge from the solar day. It is just a matter of when, and no one can accurately predict the impacts of that far in the future. The world relies on civil clocks which must by statute or implication be suitable indicators of the astronomical day. Dispensing with UTC and leap seconds will disenfranchise current and past practice, which is inconsistent with the fundamental principles of standardization. Changing the definition without changing the name would be worse than dispensing with the concept, since one could easily confuse past implementation with future definitions. Creating a new time standard exacerbates current confusion and misinterpretation.

A preponderance of respondents to the ITU-R and the formal inquiries of others has no objection to continuing with the current approach involving leap seconds; regardless, a proposed procedure for considering the redefinition of UTC is proposed. The authors suggest that UTC should be established as a normative consensus standard through an authoritative international standards organization such as ISO, this after consultation with the appropriate scientific organizations and the establishment of the legal status of UTC.

Appendix

Table 1. Pros and Cons of UTC Redefinition.

Field	Application	Points Favoring Change	Points Against Change or Favoring Status-Quo	Comments
Precision Horology	Establishing TAI, UTC	Operational complexity reduced	Reprogramming of working code required. Changing definition without changing name will invite confusion.	
Astrodynamics	Satellite ephemerides	Operational complexity reduced	Reprogramming of working code required. Extensive code changes to disambiguate UT into UTC and UT1.	Alternate independent variable should be used (TCG, TT, seconds past UTC epoch, *etc.*)

Table 1. Pros and Cons of UTC Redefinition (Continued).

Field	Application	Points Favoring Change	Points Against Change or Favoring Status-Quo	Comments
Astrodynamics Telecom-munications	Space Surveil-lance Satellite track-ing Missile track-ing / warning Satellite opera-tions	Operational com-plexity of UTC reduced	Network access to EOP values would be required for instru-ment / antenna pointing Extensive code changes to disambiguate UT into UTC and UT1. Early retirement of functional systems which cannot be up-graded Maintaining the label UTC would be confusing	Other time-labeling issues (such as change-of-year) often more problem-atic than leap sec-onds
Astrodynamics	Operational general perturbations theories (SGP4, PPT3)		Approximation error will in-crease as DUT1 increases Extensive code changes to disambiguate UT into UTC and UT1.	Legacy GP theories in common use do not differentiate between UTC and UT1 [52]
Astronomy (professional) Astronomy (amateur)	Astronomical observations Telescope control	Operational com-plexity when using UTC reduced	Network access to EOP values required for instrument point-ing Early retirement of functional systems which cannot be up-graded. Extensive code changes to disambiguate UT into UTC and UT1. Maintaining the label UTC would be confusing	
Navigation	Celestial navigation		Additional EOP values would be required to correct to UT1. Extensive code changes to disambiguate UT into UTC and UT1. Maintaining the label UTC would be confusing	
GNSS Users	Time Transfer	Simpler relation-ship between civil time and naviga-tion system time	Reprogramming of working code required; existing hard-ware may not tolerate DUT > 1 second.	Possible confusion if numerous navigation time scales all claim to provide the same thing.

Table 1. Pros and Cons of UTC Redefinition (Continued).

Field	Application	Points Favoring Change	Points Against Change or Favoring Status-Quo	Comments
GNSS Users	Positioning & Navigation	Simpler relationship between civil time and navigation-system time	Reprogramming of working code required; existing hardware may not tolerate DUT > 1 second.	Handling of relationship between civil and navigation system time already automatic and transparent to end users.
Telecommunications	Network Communications	Avoids maintenance of leap seconds on high-level servers Better facilitates synchronous communications	Reprogramming of working code required	Asynchronous communications typical, using local counters which must be reset regardless, and which are generally unaffected by leap seconds. Some cell phone networks operate on GPS time.
Telecommunications	Time transfer via timing signals (transmission)	Avoids occasional disruptions due to human / programming errors	Reprogramming of working code required	After 40 years, why do time service providers still have problems with leap seconds?
Telecommunications Networking Protocols	Time broadcast services / systems (receivers) Maintaining time on networked computers and electronic devices	Operational complexity potentially reduced over computer networks with diverse operating systems Future uncertainty & maintenance of leap seconds reduced.	Reprogramming of working code required	Computers update their time by automatic checking with a time service, since computers themselves are not accurate clocks. Many applications are not precision.
Telecommunications	Secure communications	Proximity to UT1 unnecessary	Reprogramming of working code required	Systems use non-standard, secret epochs
Air Traffic Control	Final approach Flight management	Potential to limit confusion from leap second insertions.	Reprogramming of working code required	
Emergency Services (Fire, Police, Medical) Environmental Resource Management	Positioning & Navigation	Simpler relationship between civil time and navigation system time	Reprogramming of working code required; existing hardware may not tolerate DUT > 1 second.	Handling of relationship between civil and navigation system time already automatic and transparent to end users.

Table 1. Pros and Cons of UTC Redefinition (Continued).

Field	Application	Points Favoring Change	Points Against Change or Favoring Status-Quo	Comments
Surveying & Mapping	Asset location Land management	Simplification	Reprogramming of working code required	Precision work already relies on UT1 & GPS
Geodesy	Tide modeling Earth science	Simpler relationship between civil time and Earth rotation	Complicates analytical calculation of Earth tides and ocean-loading corrections, figuring out when the GPS satellites go through eclipses, etc. Reprogramming of working code required	Requires some applications to access EOP values that did not before
Energy Management	Electric grids Power line management Oil field surveys	Proximity to UT1 not necessary Simpler representation of civil time-of-day going forward	Reprogramming of working code required	Issues related to Daylight Savings time much more problematic?
Industrial manufacturing & computing	Clock circuitry / software	Simplified designs going forward	Reprogramming of working code required	No commercial incentive to mass produce clocks that correctly accommodate leap seconds while UTC definition is uncertain
Banking & Finance	Electronic time stamps	Eliminates erroneous / ambiguous stamps during leap seconds	Software available for handling time stamps with leap seconds, but few purchase it.	Many systems have yet to conform to UTC's convention for leap seconds
Computer Science	Software Development	Simpler representation of civil time-of-day going forward	Maintaining old v. new UTC technically confusing Adds complexity to new systems due to the need for backwards compatibility Reprogramming of working code required	

Table 1. Pros and Cons of UTC Redefinition (Continued).

Field	Application	Points Favoring Change	Points Against Change or Favoring Status-Quo	Comments
Standards Institutions Academia Scientific & Technical Publishing	Standards development Professional publications Textbooks Curricula	Simplified explanation of future UTC	Large body of historical literature and knowledge base rendered obsolete Requires review, update, and republication of all documents and standards discussing timekeeping & UTC Maintaining the label "UTC" would be technically confusing	
National Governments	Statutory civil time	Removes requirements / civil liability that clocks accommodate non-uniform civil time in the short term Maintaining the label UTC would be cost effective	Statutory / regulatory changes required in nations where solar time is the (explicit or implicit) standard Maintaining the label UTC would be technically confusing	
General Public	Personal scheduling Civil time of day	Simplified representation of precision time intervals in the near term Leap second publicity ceases	Atomic broadcasts worsening representation of mean time of day Non-uniformity much worse than leap seconds eventually re-introduced into the atomic time of day Maintaining the label UTC would be confusing	General public has little need for time intervals precise to better than 1 second

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