Leap seconds: UK public dialogue – Background review

Introduction

To help design the UK public dialogue around leap seconds, OPM Group had to have clear, referenced evidence. This evidence has been used to create the Leap Seconds website and provide information for the public workshops. This short report summarises some of the findings we thought would be of interest to the public. More detailed papers and online summaries of the history and implications of leap seconds can be found on the resources page of the website. As well as reviewing relevant papers, we spoke to key people from professions likely to be affected by changes to timekeeping systems. The bibliography at the end of this report lists our sources.

Whilst containing a wealth of technical information, many of the academic papers did not explain in what ways there could be religious and cultural impacts if the international community decided to stop keeping clocks in line with the sun. We felt it was essential to begin to understand the sort of religious, social and cultural impacts so often hinted at by papers but not explained. The UK government is keen to ensure its position for the international decision is informed by the feelings of its public. In turn, the public needs to have a balanced picture of the issues surrounding the international decision on leap seconds. This balance means we have to be able to provide the public with information about cultural as well as technical considerations.

As well as lacking information about the cultural considerations around changing timescales, we have found it difficult to locate precise information about the costs of stopping or maintaining leap seconds. Experts in the area suggest international discussions have tended not to include associated costs. Instead, it appears it is accepted there were be substantial cost implications one way or the other. OPM Group is not in a position to develop further information about the overall costs.

Because we wish to be as open as possible about the sources and shortcomings of the information being used in the UK public dialogue, the following sections describe the sources of information and assess whether the information is robust or disputed. We continue to talk to people associated with the leap seconds international debate and related professions. This document should, therefore, be read as the starting point for informing our dialogue, not as the completed review of evidence.

Understanding of core concepts regarding leap seconds

This section outlines some of the core facts, considerations and historical context around leap seconds.

1. Historical development of timekeeping

Much of the literature places great emphasis on the historical importance of measuring time through celestial bodies. This literature suggests that the position of the Sun in the sky determined the passage of a day. In contrast, one interviewee argues that time scales – and possibly therefore concepts of time as a continuum – have historically been based on the moon, with an annual correction based on just one solar observation (usually a solstice).

The Egyptians were the first to attempt to measure the time of day using obelisks which served as sundials, and were the first to divide the day into 12 hours. Later, water clocks were developed; and in the 14th century, mechanical clocks were devised. In the 1930s, we developed even more precise quartz crystal clocks and in 1955 the first atomic caesium clock was developed.

Our interpretation of the literature suggests two different ways of understanding time. First, we understand a day as the full rotation of the Earth on its axis, as (initially at least) observed by the passage of the sun through the sky. Under this understanding, a day is defined relative to the Earth's rotation.

Second, we understand a day as the time it takes for a clock to move a set number of intervals – for example, the amount of time it takes for a second hand to move 86,400 times. This definition of a day is absolute – a day is the amount of time it takes for the second hand to move 86,400 times.

For almost all of history, these two methods of understanding time were interchangeable, because our measurement of the rotation of the Earth and mechanical methods of recording the passage of time were not precise enough to show any difference between the two types of time scale.

According to the US Naval Laboratory[1], caesium based clocks were first introduced in 1955. The first caesium clock, at the UK National Physical Laboratory[2], kept time to one second in 300 years. Caesium clocks quickly became adopted as the most precise standard for providing a consistent, accurate time scale. They form the basis of International Atomic Time (TAI).

2. Modern time standards

International Atomic Time (TAI, or Temps Atomique International)

TAI is calculated at the International Bureau of Weights and Measures[3] (BIPM, Bureau International des Poids et Mesures) by averaging over 200 atomic clocks in about 70 time

[1] http://tycho.usno.navy.mil/cesium.html

[2] http://www.npl.co.uk/educate-explore/factsheets/atomic-timekeeping/atomic-timekeeping-(poster)

[3] http://www.bipm.org/en/scientific/tai/tai.html

laboratories around the world. Atomic time is closely correlated with solar time, but not identical. The second in atomic time is defined as:

'The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.'[4]

The atomic second is also referred to as the SI second (Système International d'Unités). As this timescale is defined in relation to an unchanging physical property, this is an absolute definition of a second – the length of a day does not vary in International Atomic Time.
According to Kuhn[5], the length of the SI second was calculated to correlate with the length of seconds in solar time recorded in the 19th century, based on the then best estimates of the rotation of the Earth.

Universal Time 1 (UT1)

Universal Time 1 is derived from mean solar time. Mean solar time is based on the average length of the solar day – it is therefore calculated on the basis of the rotation of the Earth.

While it is difficult to measure the length of a solar day precisely, using modern measurement techniques UT1 can be determined to within 4 milliseconds[6], and is advertised as having an accuracy of within 0.1 seconds.

The Earth's speed of rotation is very slowly decreasing and is unpredictably irregular to a few parts per one-hundred-millionths of the mean solar day. There are a variety of factors that impact on the Earth's rotation, leading to two primary effects:

- Over the short term, random fluctuation: due to activity in the Earth's core, there is random fluctuation of the speed of the Earth's rotation, of +/- 5 ms.
- Over the long term, steady deceleration: the Earth is slowing down by 1.7 ms per century. As a clock, the Earth would have lost over 3 hours in the past 2000 years.

The variance of the Earth's rotation has been the subject of scientific tests since Flamsteed in 1675, who concluded that the Earth's rotation was of a constant rate, based on the best time pieces of his day. It wasn't until more precise quartz crystal clocks were developed that the variance – and deceleration – of the Earth's rotation was established.

The mean solar day is relative to the speed of the Earth's rotation. As the Earth's rotation is slowing, this means that the mean solar day, and therefore UT1, is currently slightly longer than 86,400 atomic seconds (as defined by TAI). However, a day in UT1 is still 86,400 seconds long, because it defines a second as 1/86,400 of a mean solar day.

Coordinated Universal Time (UTC, or Temps Universel Coordonné)

Because the rotation of the Earth is gradually slowing – and therefore the length of a second is different under each timescale – UT1 and TAI diverge from each other. At any given time, UT1

[4] http://www.bipm.org/en/si/si_brochure/chapter2/2-1/second.html

[5] Kuhn M. 'Leap Seconds.', https://www.cl.cam.ac.uk/~mgk25/time/leap/

[6] Finkleman D., Seago J.H. and Seidelmann P.K. (2010) 'The Debate over UTC and Leap Seconds.'

would give a different time to TAI. UTC tries to provide a time standard that avoids this divergence. UTC is the current primary time standard by which the world regulates its clocks and time.

For technical purposes, we can identify two communities of users. Astronomers, geodesists and navigators want their measure of time to be connected to the angle of the Earth's rotation in space. Physicists and engineers want a perfectly uniform scale. UTC can be seen as an attempt to satisfy both communities.[7]

A normal UTC day contains 86,400 atomic seconds (and therefore follows TAI). However, to prevent its divergence from mean solar time (and UT1 in particular), it occasionally adds or subtracts seconds ('leap seconds') to a particular day. Some days in UTC are therefore 86,401 or 86,399 atomic seconds. These 'corrections' ensure that UTC is both a precise measure of atomic time and keeps in sync with mean solar time. UTC is always kept within +/- 0.9 seconds of UT1.

Initial versions of UTC corrected the difference between UT1 and IAT by introducing 0.1 leap seconds each month.

Leap seconds

Roughly every 18 months, a leap second is introduced into UTC, the world's timescale for atomic time. A particular minute is made 61 seconds long: specifically, the UK local time 23h 59m 60s is introduced for a specific day[8].

Since 1971, there have been 25 added leap seconds, and no subtracted leap seconds.

3. Proposals to remove the leap second

In recent years, some countries and experts have expressed dissatisfaction with UTC's requirement for leap seconds (this is discussed more fully in 'Key issues surrounding the leap seconds debate').

The International Telecommunications Union (ITU) is the body with the overall international responsibility for time standards, which will make the decision on whether to retain the leap second or not at its conference in 2015. It is a UN agency.

The body within the ITU with responsibility is the Radiocommunications Sector. It has established Study Group 7, which has responsibility for time systems in relation to space operations, remote sensing (e.g. GPS) and astronomy. Sub group Working Party 7A has responsibility for coordination of time standards. This working party established the Special Rapporteur Group on the Future of the UTC Timescale, with responsibility to investigate the desirability of the leap second. The Special Rapporteur Group were asked the following study questions:

- What are the requirements for globally-accepted time scales for use both in navigation and telecommunication systems and for civil time-keeping?
- What are the present and future requirements for the tolerance limit between UTC and UT1?

[7] Nelson R.A., McCarthy D.D., Malys S., Levine J., Guinot B., Fliegel H.F., Beard R.L and Bartholomew T.R. (2001) 'The Leap Second: Its History and Possible Future'. Metrologia 38: 509-529.

[8] Finkleman D., Seago J.H. and Seidelmann P.K. (2010) 'The Debate over UTC and Leap Seconds.'

- Does the current leap second procedure satisfy user needs or should an alternative procedure be developed?

This group suggested that spacefaring activities, celestial navigation, digital time distribution systems and 'regions of the East' would all benefit from removing the leap second. They also suggested a consensus of introducing a leap hour.

A vote on whether to maintain leap seconds was scheduled for the World Radiocommunications Conference 2012 and preceeding Radiocommunication Assembly. The debate on the leap second at this conference elected to postpone voting on the issue until the 2015 Radiocommunication Assembly and World Radiocommunication Conference.

No decision has been reached on the future of the leap second.

The UK Government's position

The UK has previously consulted official bodies and agencies with an interest in precision timekeeping. None of these authorities reported significant problems arising from leap seconds, while some scientific institutions reported strong support among their memberships for retaining leap seconds.[9]

Peter Whibberley suggests that the UK Government's interest in preserving UTC is not because of any attachment to the name Greenwich Mean Time. The UK uses UTC rather than GMT as its official time scale.

The UK Government considers that the evidence collected by ITU-R Working Party 7A is insufficient to show that leap seconds are a problem and do not justify a fundamental change to civil timekeeping.

[9] Whibberley P. (2013) 'A British Perspective of the Future of Coordinated Universal Time.' ITU News.

Key issues surrounding the leap second debate

Technological considerations

Both the literature and stakeholder interviews have raised a wide range of technical considerations involved in either sustaining or suppressing the leap second, largely relating to how they might impact on computer systems. Many of these technical issues are contested on each side. This section briefly summarises some of these issues.

A range of technical issues are offered in favour of removing leap seconds from UTC. In the most general terms, a prominent concern about leap seconds can be expressed as: a system which inserts additional seconds at unpredictable intervals may be more liable to technical disruption than one that does not. This is particularly true when synchronising with other systems, as leap seconds would have to be treated identically in all cooperating systems. Specific concerns raised include:

- **Limitation of older generations of computer clocks –** some of the literature[10] suggests that certain clocks lack the capability to display '60' as a value for seconds. Some system clocks are programmed to step backwards by one second. This could create a situation where two events 1 second apart can receive identical date stamps.
- **Synchronisation between different systems**[11] – some sources suggests that if one system is maintaining UTC and another is not (or should be, but has not updated its time to reflect a leap second insertion), technical difficulties may follow. Modern data systems rely on continuous, highly accurate time.
- **Effects in the Far East**[12] – as leap seconds happen at midnight in the UK, the scope for error is reduced as financial markets (etc.) are closed. In the Far East, the scope for error is higher, as they take place during the business day.

Much of the literature relates to theoretical issues which could occur with the implementation of leap. We have identified several specific examples where leap seconds may have in fact interfered with computer systems:

- **2012 leap second** – A number of prominent websites, including Reddit, Yelp, and Qantas flight booking, were apparently affected by disruptions caused by how their systems implemented the 2012 leap second[13].
- **GLONASS navigation system** – This is the Russian system of GPS, and is a contested example in the literature of leap seconds having adverse effects. Depending on the source,

[10] Finkleman D., Seago J.H. and Seidelmann P.K. (2010) 'The Debate over UTC and Leap Seconds.'

[11] Arias F., Bartholomew T. and Lewandowski W. (2008) 'The Future of the UTC Timescale (and the possible demise of the Leap Second) – A Brief Progress Report.'

[12] Arias F., Bartholomew T. and Lewandowski W. (2008) 'The Future of the UTC Timescale (and the possible demise of the Leap Second) – A Brief Progress Report.'

[13] http://www.theguardian.com/technology/2012/jul/02/leap-second-amadeus-qantas-reddit

leap seconds were the cause of a 20 hour outage of this system or this was actually scheduled maintenance announced in advance.[14] Russian satellites are hardwired to use UTC, so the suppression of the leap second may have greater consequences for these systems. GPS itself does not use UTC.

- **Effects on Japan's Time Business Accreditation Programme**[15] – as an anti-fraud measure, Japan has developed a system that embeds a traceable time stamp (affixed by the Time Stamping Authority) in to digital documents, making it possible to identify the original and distinguish it from later copies. This system has been halted three times, due to leap seconds. The Time Stamping Authority uses many synchronized servers to perform their time monitoring services – the inclusion of sporadic, instantaneous events like the leap second mean operators have to make manual adjustments to every clock. For each leap second, the TSA have had to suspend their service (which is the standard service for businesses in Japan) for several hours at a time.

Against these technical arguments for eliminating leap seconds, the following points arise in the literature and through stakeholder interviews:

- **Upgradeability of software**[16] – Some sources suggest that the future of all civil timekeeping should not hinge on the limitations of transient technology[17]. That is, if we are confident that UTC currently configured is the optimal solution for civil purposes, then we should expect software to either adapt or use alternative time scales.
- **Existence of alternative time scales** – Some suggest that there are time scales already available for devices inconvenienced by leap seconds – such as TAI and Global Navigation Satellite System (GNSS)-based scales. Also, rather than introduce the leap second conventionally by including an additional second, some devices and systems (Google are a prominent example of this) speed up their oscillators in the vicinity of a leap second, which has a similar effect.
- **Cost of updating existing software, manuals etc.** – Many systems, particularly astronomical systems, have been designed on the basis of leap seconds. Fixing, testing and documenting all the changes to computer code and replacement of hardware that is dependent on UTC would be an enormous and costly task. In contrast, one source suggests that only a minority of software properly accounts for leap seconds currently.[18]
- **Celestial navigation**[19] **–** Some sources also suggest UTC remains highly convenient for celestial navigation. While most navigation systems now rely on satellite technology, like GPS, many organisations rely on celestial navigation as a back up. These sources suggest that celestial navigation depends on knowing mean solar time within a very strict tolerance, which makes the use of UTC highly desirable for celestial navigators.

[14] Seidelmann P.K. and Seago J.H. (2011) 'Time Scales, Their Users, and Leap Seconds.' Metrologia 48: S186-S194.

[15] https://itunews.itu.int/en/4278-Impact-of-the-leap-second-on-Japans-time-stamp-system.note.aspx

[16] Finkleman D., Seago J.H. and Seidelmann P.K. (2010) 'The Debate over UTC and Leap Seconds.'

[17] Stakeholder interview: Museum sector.

[18] Seago J.H., Seaman R.L. and Allen S.L. (2011) 'The Colloquium on Decoupling Civil Timekeeping from Earth Rotation.' (Preprint) AAS 11-660.

[19] Finkleman D., Seago J.H. and Seidelmann P.K. (2010) 'The Debate over UTC and Leap Seconds.'

However, one stakeholder[20] – with an expertise regarding the sailing community – suggested that the removal of leap seconds would not make celestial navigation much harder for sailors. This stakeholder suggested that conversion table already need producing, which are usually bought annually, and it would therefore not be difficult to account for the divergence between atomic time and the rotation of the earth in these tables if need. This stakeholder had conducted a consultation with their members, who had strongly backed keeping leap seconds.

- **Ubiquity of UTC**[21] – One stakeholder suggests that because UTC with leap seconds has been around since 1972, everyone should know how the system works. This stakeholder suspected that some in the technology industry were opposed to leap seconds because they did not trust their computer programmers to develop systems that cope with them adequately.
- **Accreditation system**[22] – One interviewee suggests that a way of improving the current system for implementing leap seconds would be to introduce an accreditation system for software – for example, using some kind of quality mark for systems that implement the leap seconds in an agreed manner.

Cultural considerations

In addition to technological considerations, many sources raise cultural issues that could arise from changes to UTC. Finkelman et al. summate the cultural nature of the change:

'Clocks everywhere—on your wall, wrist, phone and computer—would begin to diverge from the heavens. The change would bring scientific, technological, legal, philosophical and social implications too. These range from abandoning the requirement to preserve knowledge of Earth's rotation through timekeeping, to whether the word day will mean "one turn of the Earth" versus "794,243,384,928,000 cycles of cesium-133 radiation."'[23]

This section summarises the cultural issues that have arisen in our investigation of the literature and interviews with key stakeholders.

Limitations of current investigations

- There is a consensus in the literature that the discussion thus far has been limited to technical considerations and the technical community's initial thoughts on philosophical, cultural and sociological implications. Many sources identify these areas as meriting further research. One article suggests that 'position statements are lacking from elements of society that might have vested reliance or very strong philosophical preferences regarding the representation and global distribution of astronomical time of day' – e.g. the

[20] Stakeholder interview: Sailing association.

[21] Stakeholder interview: Museum sector.

[22] Stakeholder interview: Meteorology sector.

[23] Finkleman D., Allen S., Seago J.H., Seaman R. and Seidelmann P.K. (2011) 'The Future of Time: UTC and the Leap Second.' American Scientist 99: 4: 312-319.

expectations of religious concerns have been discussed, but not pursued, within the precision timekeeping community.

Measurement of time

- **Attachment to synchronicity –** multiple sources suggest that the public may well be attached to keeping civil time synchronized with mean solar time, due to every culture's history of measuring time by the rotation of the Earth and the passage of the Sun. Timekeeping based on celestial motion may well continue to be held in special regard far into the future. If we sever the connection between official timekeeping and mean solar time, it is unclear how we could return.[24]
- **Evolution of time scales –** others suggest that humanity's calendar and timekeeping systems have always evolved, and that this shows we would not be attached to the current way of calculating civil time. One counter to this is the length of time it took countries to adopt the Gregorian calendar – a full two centuries, in Britain's case[25]. One interviewee highlights that this change to time led to riots.
- **Change will not be observed in the near future –** others suggest that we would not notice the difference for some centuries. Some note the existing divergence between the mean solar day and the apparent solar day: between each equinox, the apparent solar day (i.e. how long it in fact takes for the Earth to rotate on its axis) varies by +/- 16.5 minutes. Our clocks report the mean solar day, where the day is a constant 24 hours (more or less). Yet we don't notice that sometimes the day is 16.5 minutes shorter and sometimes is 16.5 minutes longer[26]. If we were to use UTC but discontinue leap seconds, by the end of the 21st century the difference between UTC and UT1 would be around 2.5 minutes. As one source puts it:
  '*Philosophically, it is argued that the general public should remain insensitive to the secular separation of clock time from Earth orientation because the seasonal differences between apparent solar time and wall-clock time already suggest that astronomical time has limited impact on modern culture.'*[27]
- **Leap seconds will not work in the far future –** similarly, some argue that leap seconds won't be a sustainable solution forever[28]. UTC may only work for another thousand years, as beyond that point we will need more leap seconds per year than there are months in which to add them. In 50,000 years, the astronomical day will be about 86,401 SI seconds. A leap second would then be required daily.

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[24] Stakeholder interview: Museum sector.

[25] Finkleman D., Allen S., Seago J.H., Seaman R. and Seidelmann P.K. (2011) 'The Future of Time: UTC and the Leap Second.' American Scientist 99: 4: 312-319.

[26] Note: this is not the same as the periods of day and night being shorter depending on the time of year – this refers to day + night added together (a day) being sometimes shorter or longer.

[27] Finkleman D., Allen S., Seago J.H., Seaman R. and Seidelmann P.K. (2011) 'The Future of Time: UTC and the Leap Second.' American Scientist 99: 4: 312-319.

[28] Finkleman D., Allen S., Seago J.H., Seaman R. and Seidelmann P.K. (2011) 'The Future of Time: UTC and the Leap Second.' American Scientist 99: 4: 312-319.

Subjective experience of time

- **The nature of time –** Some stakeholders[29] suggested that, subjectively, the way that many people experience time is as the passage of the day, and the passing of the seasons/years. If our measurement of time ceases to reflect this, then clocks will no longer be measuring the same phenomenon that most people refer to when they talk about time.

- **Atomic time as an artificial construct**[30] – A solar day is an event that is of a self-defined duration, and which impacts heavily on everybody's lives. By contrast, it was suggested by some stakeholders that we have artificially decided how long a day should be according to atomic clocks. As such, the duration of an 'atomic day' is relatively meaningless for most people, except for the fact that it is very similar in length to a solar day. Some stakeholders felt that if the meaning of atomic time comes from the fact that it is based on solar time, then we should maintain the link between the two time systems in order to make sure that we continue to measure time in a meaningful way.

- **The gut reaction** – Many of the cultural perceptions that stakeholders raised were instinctive, rather than rational arguments. A lot of the people who we spoke to *feel* that a day ought to be measured according to the movement of the sun, because that is what the word 'day' means to them. Stakeholders sometimes reflected that while they didn't think that a loss of leap seconds would have a major impact, they nevertheless felt strongly that they wanted to keep using them[31].

Religious impacts

- **General impacts –** some sources raise the possible implications for religious groups. One source suggests that 'certain religious customs depend on actual near-term sightings of the Sun or the Moon, but when these events are obscured due to, say, local weather or topography, or when it is otherwise impractical for individuals to accomplish accurate astronomical sightings, clocks serve as intermediates'[32].
- **Impact on religious festivals –** one issue we hypothesised might be problematic for religious communities is – over the very long term – religious festivals falling on different days than they would have if we had kept our time standard in sync with solar time. One stakeholder[33] – speaking from a Christian perspective – thought that this was unlikely to be a major issue for Christians, pointing out that many different Christian communities already celebrate major festivals such as Christmas and Easter on different dates to each other. This stakeholder suggested that Islamic communities may feel differently, as a greater emphasis is placed on precise dating of ceremonies and festivals in Islam. They also felt

[29] Stakeholder interview: Archaeology sector.

[30] Stakeholder interview: Archaeology sector.

[31] Stakeholder interview: Archaeological sector

[32] Seidelmann P.K. and Seago J.H. (2011) 'Time Scales, Their Users, and Leap Seconds.' Metrologia 48: S186-S194.

[33] Stakeholder interview: Religious community.

there might be impacts on Hindus and Pagans, but didn't feel qualified to speak about them.

- **The earth as 'God's clock'**[34] **–** If the earth has been created, compete with a built in time keeping device (the sun), then that is what we should use. One stakeholder implied that it is perhaps arrogant, or insubordinate to God's creation, to create our own artificial system.

- **Our relationship to the world –** By divorcing our measurement of time from the natural rhythms of the earth, we are symbolically distancing ourselves from nature. This could have implications for the way that we treat the planet. If we consider ourselves as separate from the natural world, it is easier to abuse it, than if we feel like we are a part of it. One stakeholder argued that Christians have a duty to protect the planet earth, and as such should recognise our close connection to it[35].

- **Practical challenges for religious groups –** From the interviews that we conducted, it seems likely that most religious groups would cope practically if we stopped using leap seconds. For example:
    - To calculate Muslim prayer times, people already produce tables which everyone refers to determine when to pray. These could be made so that prayers are still synchronised to the movement of the sun.
    - Religious users of monuments such as Stonehenge are given access to the site for some time before and after the celestial event they have come to see. They watch for the event, rather than timing precisely when it will happen.

Global impacts

- **Global justice**[36] – Observations of the sun are available to all societies on the planet, and are universally understood and recognised. Some stakeholders argued that atomic time is 'owned' by a small number of countries and scientific laboratories, which places them in a position of power over other societies. This may have political implications.

- **Low tech societies** – Some stakeholders were concerned that discontinuing leap seconds may further widen rifts between high and low tech societies. Many members of low tech societies reckon the time according to the sun, and are unlikely to stop doing this if leap seconds are abandoned. This may isolate these societies by placing them on a different time system to the global standard[37].

[34] Stakeholder interview: Religious community.

[35] Stakeholder interview: Religious community

[36] Stakeholder interview: Religious community.

[37] Stakeholder interview: Religious community

Other considerations

- **Major change –** Some interviewees argued that removing leap seconds represents an extremely significant change to the way that we measure time. They felt that to make such a large change, you would need a very clear and compelling reason. They were not convinced that the technical challenges described were sufficient to warrant the change. One argued that we should make technology work for us, rather than the other way around[38].
- **Change of nomenclature[39] –** if leap seconds are suppressed, a secondary issue follows regarding what to call UTC without leap seconds. Certain sources suggest that it should remain as UTC, while other suggest a new nomenclature should be adopted as it is a technically different time scale. International Time is suggested as a possible name should leap seconds be suppressed.
- **Legislative changes –** Many countries would also have to change primary or secondary legislation in order to change to a new timescale (in some countries, irrespective of whether the new time scale was called UTC)[40]. One interviewee suggested the cost of this should be factored into the decision making process.

[38] Stakeholder interview: Archaeological sector

[39] Whibberley P. (2013) 'A British Perspective of the Future of Coordinated Universal Time.' ITU News.

[40] Whibberley P. (2013) 'A British Perspective of the Future of Coordinated Universal Time.' ITU News.

Bibliography

Sources of evidence

This section details the key documents, online content and stakeholder interviews we studied while conducting this review.

Academic articles and policy papers

- Arias F., Bartholomew T. and Lewandowski W. (2008) 'The Future of the UTC Timescale (and the possible demise of the Leap Second) – A Brief Progress Report.'
- Behrendt K. and Fodero K. (2005) *'The Perfect Time: An Examination of Time-Synchronization Techniques.'* Schweitzer Engineering Laboratories Inc.
- Birth K.K. (2013) 'The Princess and the Pea: Research Strategies for the Study of the Mediation of Timescales by Artifacts.' AAS 13-516.
- Birth K.K. (2013) 'Zmanim, Salat, Jyotish and UTC: the Articulation of Religious Times and the Global Timescale.' AAS 13-517.
- Dick W.R. (2011) 'The IERS, the Leap Second, and the Public.' AAS 11-667.
- Finkleman D., Allen S., Seago J.H., Seaman R. and Seidelmann P.K. (2011) *'The Future of Time: UTC and the Leap Second.'* American Scientist 99: 4: 312-319.
- Finkleman D., Seago J.H. and Seidelmann P.K. (2010) *'The Debate over UTC and Leap Seconds.'*
- Nelson R.A., McCarthy D.D., Malys S., Levine J., Guinot B., Fliegel H.F., Beard R.L and Bartholomew T.R. (2001) *'The Leap Second: Its History and Possible Future'*. Metrologia 38: 509-529.
- RAS. Royal Astronomical Society. (2005) 'Statement on Use of Leap-seconds in Coordinated Universal Time.'
- Seago J.H., Seaman R.L. and Allen S.L. (2011) *'The Colloquium on Decoupling Civil Timekeeping from Earth Rotation.'* (Preprint) AAS 11-660.
- Seidelmann P.K. and Seago J.H. (2011) *'Issues Concerning the Future of UTC.'* (Preprint) AAS 11-672.
- Seidelmann P.K. and Seago J.H. (2011) *'Time Scales, Their Users, and Leap Seconds.'* Metrologia 48: S186-S194.
- Whibberley P. (2013) 'A British Perspective of the Future of Coordinated Universal Time.' ITU News.

Online articles and other content

- Allen S. *'The Future of Leap Seconds.'* Web link (accessed 04/2014): http://www.ucolick.org/~sla/leapsecs/onlinebib.html
- ITU/BIPM Workshop *'Future of the International Time Scale.'* Geneva. 19-20 September 2013. Web link (accessed 04/2014): http://www.itu.int/ITU-R/index.asp?category=conferences&rlink=itu-bipm-workshop-13&lang=en
- Kuhn M. *'Leap Seconds.'* Web link (accessed 04/2014): https://www.cl.cam.ac.uk/~mgk25/time/leap/

- Requirements for UTC and Civil Timekeeping on Earth: A Colloquium Addressing a Continuous Time Standard. Web link (accessed 04/2014): http://www.cacr.caltech.edu/futureofutc/

Stakeholder interviews

Interviewee	Sector
1	Meteorology
2	Museum
3	Technology company
4	Journalist
5	Sailing association
6	Religious community
7	Religious community
8	Cultural heritage
9	Archaeology

Other sources

Our initial inception meeting with the Oversight Group provided us with varied information about leap seconds, as well as suggesting multiple avenues of further research at the beginning of our investigations. We also subsequently met with representatives from the National Measurement Office and Peter Whibberley of the National Physical Laboratory, who had agreed to test our knowledge, as well as providing further insights and extension of our understanding.