London Review of Books

Plus or Minus One Ear

Steven Shapin

World in the Balance: The Historic Quest for an Absolute System of Measurement by Robert Crease
Norton, 317 pp, £18.99, October 2011, ISBN 978 0 393 07298 3

The geeks at the Massachusetts Institute of Technology are fond of merry japes, locally known as 'hacks'. One of the more memorable happened one night in October 1958 when an MIT fraternity had the idea of initiating new members by making them measure a bridge over the Charles River connecting the Cambridge campus with Boston. Crossing the bridge was often a wet, windy and unpleasant business and it was thought that students returning at night from downtown would like to know, by visible marks and with some precision, how far they still had to go. The older fraternity brothers decided to use one of the new pledges as a rule, and selected Oliver R. Smoot, the shortest of the lot at 5ft 7in. The other pledges laid Smoot out at one end of the bridge, marked his extent with chalk and paint, then picked him up and laid him down again, spelling out the full measurement every ten lengths, and inscribing the mid-point of the bridge with the words 'halfway to Hell'. In this way, it was determined that the span was 364.4 smoots long, 'plus or minus one ear' (to indicate measurement uncertainty).

The hack was too good to let fade away, so every now and then the fraternity makes its pledges repaint the markings. You might think this isn't the sort of vandalism the police would tolerate, but they do. The smoot markings soon became convenient in recording the exact location of traffic accidents, so (as the story goes) when the bridge walkways needed to be repaved in 1987, the Massachusetts Department of Public Works directed the construction company to lay out the concrete slabs on the walkway not in the customary six-foot lengths but in shorter smoot units. Fifty years after the original hack, the smoot markers have become part of civic tradition: the City of Cambridge declared 4 October 2008 'Smoot Day'. MIT students ran up a commemorative plaque on a precision milling machine and created an aluminium Smoot Stick which they deposited in the university's museum as a durable reference standard: the unit-smoot is now detached from the person-Smoot. Through the legions of MIT graduates driving global high-tech culture, the smoot has travelled the world. If you use Google Earth, you can elect the units of length in which you'd like distances measured: miles, kilometres, yards, feet – and smoots.

The history of the smoot recapitulates much of the deep history of measurement standards. Most stories about the emergence of length measures track back to the human body. The cubit ran from the elbow to the fingertip; the yard was the distance from the tip of an outstretched hand to the middle of the chest (or to the tip of your nose); the fathom was the distance between the extremes of a person's outstretched arms, and the ell (an abbreviation of elbow) was traditionally an arm's length, though English, Scottish and Flemish ells were reckoned differently. Human bodies and their parts vary in size and so do the measures derived from them.

Central European foot measures generally ranged from $10^1/2$ to $12^1/2$ modern inches, but the Sicilian foot was 8.75 inches and the Genevan foot 19.2, so we can't be certain that all foot standards really did come from any human foot. Maybe the Genevan or even the 12-inch foot belonged to heroic specimens, or maybe the original foot measure included a generously proportioned shoe. Maybe both human feet and the length that the foot measure measured increased over time. Maybe too there were other ways of establishing the foot. Sixteenth-century writers claimed that French workmen calculated it by joining the extremities of their thumbs, clenching the fingers, and extending the thumbs as far as they could. Try it yourself and you'll see that you can get pretty close to a 12-inch foot. The concept of the 'average foot' (understood as the mean of the population) probably wasn't intelligible before the emergence in the 19th century of the notion of the 'average man', but a 16th-century German source reported an ingenious way of arriving at a reliable foot measure: lurk outside church on Sunday and, when the worshippers come out, ask 16 men to stop – both short and tall – and make them line up their left feet, one after the other. The length you get will constitute the local land measure called the rood, and a sixteenth part of that 'shall be the right and lawful foot', even if it corresponds to the foot length of no one of the 16. Similarly, one story about the inch says that it was taken as the width of a man's thumb at the base of the nail, and another derives it from the Latin word for a twelfth (*uncia*), as in $^1/12$th of a foot is an inch and $^1/12$th of a Troy pound is an ounce.

Length units could be systematically related because bodily dimensions were understood as organically related. 'Man is the measure of all things,' and Leonardo's Vitruvian Man represented confidence in the proportionality of human body parts: 'The length of the outspread arms is equal to the height of a man; from the hairline to the bottom of the chin is one-tenth of the height of a man; from below the chin to the top of the head is one-eighth of the height of a man.' Tailors as well as artists knew some of these systemic relations: the Lilliputian seamstresses in *Gulliver's Travels* measured up their giant guest using a rule of thumb – 'twice round the thumb is once round the wrist.' The human body was a cosmologically and aesthetically resonant measuring-kit. It was metrically intelligible, useful and, above all, it was at hand. 'Traditional measures were "human" in many respects,' the Polish historian Witold Kula wrote in his great study of *Measures and Men*. 'They were expressive of man and his work.'

But anthropometric units don't get you very far in measuring volume, weight and time. Any appropriately shaped vessel whose general dimensions were recognised by a relevant community could serve as a volume measure and, it might be expected, as a measure of the weight of stuff the vessel contained. The passage of time might be measured in many ways: by the length of a day, and parts thereof, in which case you wouldn't be greatly bothered by annual variation; or by reference to noon, solstices, equinoxes and lunar motions; or by the amount of time it took to perform some locally well-understood task – for example, how long it took to cook a pot of rice or plough a furrow.

Intelligibility, accessibility and at-handness were among the virtues of traditional measures; among their vices were their variability, imprecision and the difficulty of converting between them. Travelling through France just before the Revolution, Arthur Young was distressed at the 'infinite perplexity of the measures' used: 'They differ not only in every province, but in every district and almost every town.' A quarter of a million distinct units of weights and measures were employed in different parts of the country. Worried by the high price of grain in 1796, the British government was concerned that uncontrollably varying systems for measuring it out were contributing to political unrest – 'an evident fraud on the consumers of bread, and an advantage to none but the jobbers in corn, who, from practice, are as well acquainted with the size of every farmer's bushel as with his face.' From long experience, and with much effort, the wide-boy jobbers might come to know the difference between the bushels used in Winchester and Basingstoke, but those whose sphere of familiarity was more restricted might not. And even in Basingstoke, the ordinary purchaser might get a nine-gallon bushel while, in 'a shameful fraud on the consumer', a gentleman might get $10^1/2$ gallons. A bushel for measuring wheat could be a different size from one for measuring barley. And bushels of the same volume might contain different amounts of grain if they were heaped or levelled, filled from a greater or a lesser height. You might heap a bushel if the grain was of low quality or you might do it if the purchaser was of high quality. Not all grain was the same and not all transactions between people were the same. Traditional measures persistently linked quantity and quality.

You use standards to measure – and that's a practical matter – but measures are not merely more or less, they may be just or unjust. There is no way to disentangle their instrumental and moral aspects. Standards were norms, just as the Roman *norma* was a tool for obtaining right angles, the usage later extending to standards of right moral action. God traditionally kept standard weights and measures in his kit: 'A just weight and balance are the Lord's,' Proverbs said: 'All the weights of the bag are his work.' He created the world by ordering 'all things in measure and number and weight' and his measures were an index of justice: 'Thou shalt not have in thy bag divers weights, a great and a small. Thou shalt not have in thine house divers measures, a great and a small.' Ancient and medieval thought ran together the notion of measure and moderation – proportion, due measure, just measure. Double standards were no standards at all. The scales held by Lady Justice on top of the Old Bailey express both unbiased scales and an unbiased weigher. (This Justice, atypically, is not blindfolded because she is taken to personify fairness.)

God kept weights and measures in his bag, but in human society the objects tended to be enshrined in the houses where authority lived – on the Acropolis, on the Capitoline Hill, in the Temple at Jerusalem, in Hagia Sophia in Constantinople, later in the seats of secular government and in institutions linked to government. The Saxons kept their standards of volume – bushel, peck, quart and gallon – at their Winchester capital and the Normans then had them removed to Westminster Abbey. In medieval Europe, you could check your rule against metal rods built into the walls of churches or other public buildings. Just to the left of the main entrance to the cathedral of St Stephen in Vienna are two iron bars embedded in the wall – the linen ell and the shorter drapery ell. If you were a visitor and wanted to know local standards, or if you wanted to check your local rules against the references, there they were. And if you needed to be reminded of their authority, there it was.

Variability and imprecision were long-standing problems that might have local solutions, if indeed they were seen as problems at all. This is the point at which Robert Crease's *World in the Balance* gets going. He is indebted to Kula, as is every recent historian writing about measurement and modernity, but he takes the story onwards, dealing in more detail with 19th and 20th-century metrology and its engagements with local variation. How did we get from the body-reference yard to the artifact-standard of a metal metre bar in Paris, to the metre as 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and 5d5 of the krypton-86 atom, to its present official definition as the length of the path travelled by light in vacuum in 1/299,792,458th of a second? Every modern scholar now accepts that the seeming banality and just-so-ness of standards mask massive contingency and bloody struggle in their establishment and maintenance, recognising, as the historian Ken Alder puts it, that 'the price of standards is eternal vigilance.' Contingency and struggle were the drivers of Thomas Pynchon's great metrological novel *Mason & Dixon*, as they are of Crease's book, whose special strength is attention to the last several decimal places of modern measurements, how they were arrived at through the 19th and 20th centuries, why and to whom these things mattered.

The first move away from metrological tradition was to cut down the heterogeneity: it's easier to govern a country with 246 varieties of cheese – which De Gaulle thought was hard enough – than with many different weights, measures and time systems. Effective rule needs stable rulers. That sensitivity to the link between standardisation and governance at a distance developed much earlier than the French Revolution and the metric system. Magna Carta declared that 'there be one measure of wine throughout our whole realm ... and one measure of corn ... and one width of cloth ... of weights also let it be as of measures.' What was an irritant in transactions between millers in Winchester and buyers of flour in Basingstoke became intolerable in governing a nation-state from London or Paris. The ability of standards to act over a distance was useful if you meant to govern over a distance.

The standardisation of the coinage was the most visible of these concerns, with its attendant enshrinement of reference standards, the establishment of assay offices, standard-marks warranting composition and judicial arrangements for punishing counterfeiters. In England, the legal definition of composition standards was promulgated after Magna Carta but the regulation of purity standards was probably Saxon. You can't govern if you can't control your currency, so metallurgical standards and their enforcement are tools of statecraft. So too is the ability effectively to levy taxes – and to make visible their material and legitimate bases.

The power of the British state, its capacity to wage war and extend empire in the 18th and 19th centuries, was dependent on excise taxes, and especially the excise on alcohol: government ran on alcohol in more than the usual sense. Yet the state's ability to enforce and collect that excise was itself dependent on developing instrumental practices objectively to establish alcoholic proof. The excise was widely hated, resisted and often subverted, so, as one assayer put it in 1801, 'a standard alone can put an end to this contrariety of opinions.' Crease doesn't discuss the use of standards in the excise, but fine historical work by William Ashworth has described the struggle over determining proof standards during the 18th and 19th centuries and the role of both bureaucratic procedures and the specific-gravity measuring instrument called the hydrometer in producing the 'practical objectivity' that underwrote empire.

The historical trajectory of standards, Crease notes, is often described as *disembodiment*, as in the detachment of the smoot from Smoot. But under another description that process is a different kind of embodiment, the transference of standards from flesh to metal. An official ell or Troy pound just was the reference bar or lump constituted as such; it was the artifact that gave meaning to the ell-ness or pound-ness of all other things an ell long or a pound in weight – and that is the sense in which Wittgenstein said: 'There is *one* thing of which one can say neither that it is one metre long, nor that it is not one metre long, and that is the standard metre in Paris.' It was both handy and politically necessary that the state keep, guard and guarantee artifactual reference standards, and that is what was done until, in the course of the 18th and 19th centuries, grounds of dissatisfaction emerged.

Discontent took several forms. One concerned the practices of reference which the artifacts were intended to ensure. The standard artifact, kept in one place, had to generate authentic copies – sometimes technically called 'witnesses' – in order to circulate, and yet, with demands for greater and greater precision, both its physical use as a reference and its physical instability over time were gradually understood to compromise its integrity. Every time you took the artifact out to use it as a reference, you endangered its integrity, and even the physical environment in which you kept it safe might, over time, have unpredictable effects on its length or weight. A metal bar might bend; a metal weight might corrode. Metallurgical improvements were made, but you could never be absolutely certain of long-term stability. In 1948, it was discovered that the 'Kilogram of the Archives', fabricated in 1799 and carefully looked after since then, had lost weight, evidently (as Crease writes) 'due to the escape of bubbles' trapped in the metal. Uncontrollably varying reference standards aren't what you want. Nor do you want them to be lost or destroyed. But this happens. Artifact standards of length and weight, designed in the mid-18th century and designated as the first imperial standards in 1824, were kept in the House of Commons – until it burned down ten years later, severely damaging the standards and rendering them useless. What authorities longed for was an order of standards that wasn't defined by any physical artifact or patterned on the human body, wasn't the conventional outcome of human history or geared towards any particular practice, whether it was milling or carpentry or ploughing. They wanted standard measures that reflected the order of reality, standards that could be reproduced anywhere, at any time – even if all the existing metal bars and weights and clocks ceased to exist.

The French invention of the metric system in the late 18th and early 19th centuries was a big deal mainly because it allowed easy, and, it was said, intelligible interconvertibility of units. What was intelligible and systematically easy would be naturally fit for global use. Moving from inches to feet to yards to miles means multiplying first by 12, then by 3, and then by 1760, whereas, of course, every metric conversion proceeds by tens and its multiples and there are only a few prefixes designating scale – kilo, centi, milli, micro etc. Metrication made many calculations much easier, but the problem of reference standards remained. What if, however, you could tie measures not to a human artifact but to the invariant order of terrestrial reality? If you could do that, you would no longer be dependent on the integrity of a particular physical object. Essentially, anyone, anywhere, could reproduce the standards. At that point, standards would be not only nationally and globally uniform; they would be as stable as reality itself, finally disembodied.

It was a project that ultimately succeeded, though not without difficulties and never totally. In fact, the original metre was supposed to be a natural standard, nothing to do with fingers, arms and noses, everything to do with unvarying features of the terrestrial world, and intended to be used by all people, everywhere. As Alder puts it, 'it was only fitting that a measure for all the world's people be based on a measure of the world.' The metre would be one ten-millionth of the distance along a meridian passing through Paris between the North Pole and the equator. That length was picked for historical reasons – because it was estimated to be pretty close to a traditional unit, the Parisian *aune*. (This 'rational' measure was therefore, as economic historians say, 'path dependent': it took its form partly because of its intercalation in the past history of human practices.) The problem with a natural standard for the metre, as more fully documented in Alder's sparkling book, *The Measure of All Things* (2002), was, on the one hand, the fallibility of the scientists sent to perform the meridional measurements and, on the other, the annoying irregularity of the Earth's shape, not corresponding exactly to any theorised geometrical figure.

The late 18th-century attempt to establish the metre as a natural standard did not succeed, but in 1799 the 'good-enough-for-government-work' measure was nevertheless embodied in a platinum alloy bar, the so-called 'Metre of the Archives', and it was this artifact that continued as the reference standard for most of the 19th century, despite the fact that it was known not to correspond precisely to the one ten-millionth of a quarter-meridian criterion. In 1889, new, more stable physical artifacts were constructed: the prototype metre was now an alloy of 90 per cent platinum and 10 per cent iridium, measured at the temperature at which ice melts. The further adoption of the metre was commended not because of its naturalness but because, for a host of political, cultural and scientific reasons, it had already become (as *Nature* said) 'a cosmopolitan unit, widely recognised, and in general use among many nations'. Or, as Crease writes, 'the metre was universal because it was universal.' Custom, convention and artifact had not been eliminated, they had been relocated to a new metrological language, a new set of artifacts, and a new group of administrative bodies that would articulate and enforce standards.

The quest for natural standards was soon to succeed. From the end of the 19th century, the financial resources and organisational energies dedicated to achieving the final dream of standards that flowed from the structure of reality grew enormously. Both governmental and non-governmental metrological commissions proliferated: 17 countries at the General Conference of Weights and Measures in 1875 signed up to the Metre Convention, establishing both a physical institute to house the standards and periodically meeting supervisory bodies. The world had international metrological government long before it had the League of Nations. In 1960, an international commission of metrologists established the krypton-86 spectral line definition of the metre, and in 1983 further exactitude was secured through its redefinition as the distance travelled by light in a precise span of time. The physical standard, at that moment, 'became a historic object; the new standard was universal, everywhere, not localised'.

In 1887, an American scientist, William Harkness, thrilled to the prospect that the world would soon have natural metrological standards, reproducible not just in the absence of the usual artifacts but even on distant worlds after the Earth itself had fallen into the Sun and been vaporised. The science of the 17th and 18th centuries could not do that, but today we can, since modern metrologists can derive natural standards by connecting their units 'with the ultimate atoms which constitute the universe itself'. No one would now have to go to Paris to check out a metal bar; by the middle of the 20th century 'any country could realise the metre, provided it had the technology.' All that's needed to achieve this reproduction are a few simple scientific instruments – a pretty good diffraction grating, a goniometer (to measure angles), and the appropriate spectroscopic apparatus. That is to say, you just need a well-equipped physics laboratory, staffed by physicists rigorously trained in similarly equipped laboratories, and having access to the supervisory and regulatory bureaucracies which would vouch for and enforce the standards thus reproduced. Natural and universal standards are, in this way, locally dependent on a very particular material and organisational culture. To reproduce natural standards you just have to re-create a big chunk of modern human culture. The standards have not escaped history; they are rather markers of where history now is.

Attaining these standards was a heroic cultural achievement. What has to be celebrated, however – if celebration is intended – are not just heroic metrologists but much of the fabric of the modern political and commercial order. In a coda addressing what he calls the 'dark sides of the metroscape', Crease reflects on the social distribution of modern metrics. While in the past 'metrological matters were never really in the hands of the average citizen,' he says, 'comprehension generally was.' Modern metrological units, he writes, are easy to apply, while understanding their bases has become 'too complex for all but scientists to grasp'.

No reason for nostalgia. We used to live in a world, it's said, that had different measures, but we still do. It's not just that planes continue to fly around the world at 30,000 feet rather than 9,144 metres (except in China, Mongolia, North Korea, Russia and a few of the former Soviet republics) and that Americans haven't a clue how hot it is when it's 31°C or how heavy people are when they weigh 12 stones – a unit which a table in Crease's book equates to 14 ounces. It's also that we continue to use all sorts of traditional and locally varying measures for all sorts of everyday purposes. Horses continue to be hands high. A dozen bagels on the Upper West Side of Manhattan counts out at 13. I make risotto by filling up a certain saucepan with stock; I have no idea how much stock that is, but it works well and I've screwed up when cooking risotto in someone else's kitchen. When I go to buy a small rug, I pace out its dimensions with my feet and only if the result is ambiguous do I go get a tape measure.

The 19th and 20th-century drive to precision and to homogeneity of all sorts of standards – quantitative and qualitative – was powered by a range of practices that deliver us the goods and services we want and whose ability to do so depends on effective action over very long distances and exquisitely precise co-ordination of things and people. The origins of the present-day International Organisation for Standardisation – former president Oliver R. Smoot – trace back to late 19th-century concern among engineers over the specifications of nuts and bolts. Telegraphic communication went better with internationally agreed standards of electrical resistance; the railroads called for national and international standards of time; manufacture of goods through interchangeable parts depended on metrical standards for precision engineering; burgeoning road traffic generated demands for national, and later international, standard signage; and that curiously placeless place, the modern airport, was one of the sites in which we learned how to interpret those odd icons guiding us to the appropriately gendered toilet.

During the 1914-18 war, the Fabian socialist Leonard Woolf spoke in praise of the largely voluntary international organisations that had given the world standards of length, weight, colour, electrical resistance and agricultural produce; he celebrated an 'international commission for unifying the nomenclature of apples', and he looked forward to a bright future in which 'even our chickens will be internationalised.' The worlds of science and commerce had shown the way to a harmonious international order in which voluntarily arrived at standards would embody reason, enhance productivity, eliminate confusing and unfair local customs, ensure peace and co-operation, and be guided by the wise counsel of technical expertise. A pattern of rational international governance had been established; modern metrology virtuously modelled modern political order; and the world had finally been made to measure.

Vol. 34 No. 16 · 30 August 2012 » Steven Shapin » Plus or Minus One Ear
pages 8-10 | 4511 words

 ^ Top