Chapter 12

Problems With US Measures

Because there has never been a top-to-bottom analysis, and reform of US weights and measures, a large number of inefficiencies and irrational usage occurs. The inability of our political system to provide much needed reform, perpetuates the problems.

Roadways in the US are measured out in chains. A chain is a unit of measure. In the US we use Gunter's chain. Because of this, there are ten square chains in an acre. Chains are also marked in decimal feet. In other words, the base unit for the chain is the US foot. All the roadways in the US are measured, surveyed, and constructed in chains, or decimalized feet. There are no inches.

However, when another government agency designs a bridge which is to connect with this highway, that bridge is designed and built in feet and inches. This offers opportunity for error that one does not encounter when one uses millimeters only.

One needs fasteners for construction, and those which most people in the US encounter are shown in Table 12.1. The screw designations appear cryptic to anyone who first encounters them, and in many cases to people who have used them for many years. Often long time users are unaware what the number (#) designations signify. The reason there are two types of designations is because US screws are a concatenation of two separately developed designations into one "standard." The number designations are essentially gauge numbers. The term gauge is completely vacuous, and so devoid of meaning, that the word is generally allowed on metric drawings. These gauge numbers are proxy designations for a diameter in inches. The number after the dash is the number of threads per inch on the screw. For instance a 6-32 screw is a screw

US Screw Designations
#0
#1-64
#2-56
#3-48
#4-40
#5-40
#6-32
#8-32
#10-24
#12-24
1/4-20
5/16-18
3/8-16
7/16-14
1/2-13
9/16-12
5/8-11
3/4-10
7/8-9
1-8

Table 12.1: Table of US Screws

Screw Designation	**Drill**
M1	1 mm
-	1.1 mm
M1.2	1.2 mm
-	1.3 mm
-	1.4 mm
-	1.5 mm
M1.6	1.6 mm
-	1.7 mm
-	1.8 mm
-	1.9 mm
M2	2 mm
-	2.1 mm
-	2.2 mm
-	2.3 mm
-	2.4 mm
M2.5	2.5 mm
M3	3 mm
M4	4 mm
M5	5 mm
M6	6 mm
M8	8 mm
M10	10 mm
M12	12 mm
M16	16 mm
M20	20 mm
M24	24 mm
M30	30 mm
M36	36 mm
M42	42 mm
M56	56 mm
M64	64 mm

Table 12.2: Table of Metric Screws and Drill Bits Diameters Note: Drill bit sizes above M2.5 have not been included for brevity

with a number six gauge diameter, which is 0.1380 inches, with thirty-two threads to the inch.

The second set of designations are in terms of fractions of an inch, and the number after the dash is the same as before, the number of threads per inch. The common 1/4-20 screw has a diameter of 1/4 inch (0.25 inch) with 20 threads per inch.

Because the screws used in the US are a the combination of two sets of arbitrary industrial designations, they at one time overlapped. It is still possible to obtain #14 and #16 screws. The #14 screw is very close in diameter to the 1/4 inch screw, and so to make the two designations "compatible," or more accurately non-overlapping, it was decided to use the gauge number designations until 1/4 inch and then use the fractional designations afterward.

In order to prepare a construction material for a fastener, one needs to create a hole through which it is to pass. This is generally done with a drill and drill bit. There are two different sets of sizes for US drill bits. The first is the fractional-inch size bits. The second is US Number and Letter Gauge bits. Neither directly expresses their diameters directly as a decimal.

If one wishes to drill a hole which is the same diameter as a chosen screw (this is often called a "friction fit") it is simply not possible with common US tooling. The drill bit sizes were developed independently of the screw diameters. This is the difference between an integrated system and an uncorrelated set of tooling.

The designations for metric screws and the sizes of metric drill bits are given in Table 12.2. The assortment of metric drill bit sizes has been truncated after 2.5 mm for brevity. The designation for metric screws is simple, it has an M for metric, and then a number which is the diameter of the screw in millimeters. So an M5 screw is five millimeters in diameter, and so a 5 mm drill bit would produce a friction fit 5 mm hole. If the pitch in mm is not designated, then the screw is assumed to have standard coarse threads. The standard M5 screw is assumed M5 x 0.8, M5 x 0.5 is the designation for fine thread.

The metric system is in fact a system, the sizes of tools have been carefully crafted to integrate with one another. The sizes chosen are generally based on what are known as *preferred numbers*. In 1877, the French Engineer Charles Renard (1847-1905) was instructed to look into improving captive balloons. These stationary, moored balloons were then in use by the French military, and of great importance. What Renard discovered, was that 425 different sizes of cable were being used to moor these balloons. Clearly this large number of cables was not required from the outcome of any Engineering analysis, and were a nightmare to inventory and procure.

Renard determined that for mooring balloons, the most important inherent property of these cables, is their mass per unit length. He was able to develop a mathematical relationship which allowed him to replace the 425 sizes of cable with 17, which covered the same engineering range of requirements.

Renards geometric series was a perfect fit for a base 10 decimalized system, as it starts with 10 and ends with 100. The system Renard had in mind when he developed his series was, of course, the metric system. This series produces what are proverbially known in engineering circles as preferred numbers (also called preferred values). Renards system was adopted as an international standard, ISO 3, in 1952, and are appropriately referred to as a Renard Series, or R Series. A similar series, the E series, is used to determine the values of electronic resistors, capacitors, inductors and zener diodes.

When metric was introduced into the building industry, a choice of dimensions which could easily be manipulated in ones head was thought best. Grid lines on metric construction drawings are multiples of 100 mm. This is the basic "module," and the center to center of major dimensions are to be multiples of this value, which is denoted as M. Therefore 3M = 300 mm, 6M = 600 mm and 12M = 1200 mm or 1.2 meters. A multiple of 600 mm (6 M) can always be divided by 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 25, 30, 40, 50, 60, 75, 100, 120, 150, 200, and 300, each of which is an integer number of millimeters. Because 600 mm can be evently divided 22 ways, the distance between studs is chosen as 600 mm. This allows for building construction without decimals. In storm prone regions, sometimes 400 mm stud spacing is used, with 2, 4, 5, 8, 10, 16, 20, 25, 40, 50, 80, 100, and 200, as factors that produce 13 round divisions of the 4M metric module.

The introduction of metric is a perfect opportunity to introduce much needed reform into different trades. An example which illustrates the savings one can obtain by using preferred numbers, occurred in Australia. When metric was introduced into an Australian Ford car plant, the number of fasteners used by Ford were reduced by a factor of four after metric conversion. The implementation of metric threads reduced the hodgepodge of bolts by 88%, and nuts by 72%. The number of sheet metal thicknesses in some factories were considerably reduced, which saved on inventory costs, and had no impact on Engineering design options. According to Kevin Wilks in his book *Metrication in Australia*: "When standardizing containers, Australia was able to reduce the number of can sizes, for packing goods sold by mass, from approximately 90 to 30." He goes on: "Another example in wholesale packaging concerned corrugated fiberboard cases for packing fruit. With the establishment of metric packing quantities the opportunity was taken to reduce the variety of shapes and sizes from many hundreds to about 50."

As previously mentioned, the word *gauge* if often used to describe different materials. There are at least 14 different definitions of the word gauge. There are 12 gauge shotguns, railroad gauge, drill bit gauge, stubs iron wire gauge, sheet metal gauge, film gauge, loading gauge, structure gauge, and they are all needlessly uncorrelated with one another. The word gauge is also used to describe devices that do the measuring, such as an air gauge, rain gauge, gauge blocks, water gauge, weather gauge, needle gauge and tire gauge. The thickness of metal sheets are in gauge values and are not correlated with the thickness of sheets of plastic. There are gauge sizes where, as the gauge becomes larger, the quantity becomes smaller, and others that become larger with gauge number.

One of the most meaningless, is American Wire Gauge, which was adopted in the US around 1857, and is used for conductive wire. An abbreviated list of American Wire Gauge and the diameter of the wires in inches is given in Table 12.3

American Wire Gauge is inversely proportional to the gauge number, so larger gauge numbers mean smaller values of diameter. Metric wire has a diameter directly in millimeters. Some common values are given in Table 12.4. For conductive wire, the electrical resistance is proportional to the cross-sectional area of the wire, and this is another way to describe it. In either case the diameter is in millimeters or area in square millimeters (mm^2)

Copper thickness on printed circuit boards is not given in inches in the US, but by a proxy value in ounces. The number of ounces per square foot is the designation, although the primary dimension of interest for electronic design work is the copper thickness.

AWG Number	Wire Diameter (inch)
1	0.2893
2	0.2576
3	0.2294
4	0.2043
5	0.1819
6	0.1620
7	0.1443
8	0.1285
9	0.1144
10	0.1019

Table 12.3: American Wire Gauge

Wire Diameter (mm)
0.5
0.7
1.0
1.5
2.0
3.0
4.8

Table 12.4: Abbreviated Table of Metric Wire

Perhaps one of the best examples of poor practice by US industry is that of electronics. As electronics continued to miniaturize, electrical components were packaged into *surface mount devices* (SMD) also called chip components. Industry consultant Tom Hausherr points out that:

> All the World Standard Groups involved in the electronics industry (IPC, IEC, NIST, JEDEC, EIA & JEITA) have made the transition to the metric measurement system. They formed an alliance to stop using English units and all the data they publish is in metric units.

In the 1980s, the world standards organizations banded together and produced worldwide metric standards. The Electronics Industries Alliance (EIA) in the US was given the responsibility to articulate the size of surface mount devices. The world had created all the standards in metric, and the EIA was to publish the new metric dimensions for all to use. A book was printed with all the component names, dimensions and other pertinent engineering data. It was then released to US manufacturers for implementation.

American component manufacturers refused to make components to metric dimensions. The PCB assembly and etching houses rejected metric dimensioned drawings, and spurned any thought of using them. They repeatedly demanded the EIA publish a version of the standard with US (inch) units. The EIA finally did this and *unilaterally* changed the names of the components.

The metric SMD components were now renamed using inches. Originally, the first two numbers of the chip component names are the SMD length in mm, and the second two are the width in mm. There is an assumed decimal point between each set of paired numbers. For example 3216 is 3.2 mm x 1.6 mm. A short list of the renaming is given in Table 12.5

The 3216 is renamed 1206, which is 0.12” x 0.06”, with an assumed decimal point at the front, and whatever conversion factor error is introduced. We can see this US “improvement” introduced *identical* name designation for different size electronic SMD components. After this renaming, should you be interested in specifying an 0402 or 0603 device, one now has the opportunity for a metric/inch nomenclature mistake, which could precipitate lost time and money.

When the world standards committees discovered what the EIA had done, they released an order for the EIA to cease publication of this

Millimeter	Inch
0402	01005
0603	0201
1005	**0402**
1608	**0603**
2013	0805
3216	1206
5025	**2010**

Table 12.5: SMD (chip component) millimeter and non-standard inch designations. The unilateral renaming of chip components by US industry had created identical names for different sized parts. The designations which cause confusion are in bold.

non-metric document. The EIA was reminded they were in violation of the international agreement they signed with all the world standards bodies, agreeing NEVER to publish ANY standards using English units. In 1991, the EIA stopped publishing the feral document, and because of this, there is no longer any official standard followed in the US. The EIA ceased operations on February 11, 2011.

The US component manufacturers, and PCB etching houses, returned to the days of the perch, furlong, and barleycorn. With no standard to follow, SMD manufacturers began to game the situation. There were no longer standards for capacitors or inductors, or common three leg transistors known as SOT23. So 20 different sizes of these small outline transistors (SOT23) appeared. Chaos ensued. Rather than impose order by standards regulation, or metric adoption, the US industry just tried to figure out a way to name the multitude of these ad hoc non-interchangeable “standard” parts in Olde English.

The rest of the world embraced metric measurements, and metric standard electronic parts. If you are in Germany and order parts from Japan, or Korea, or Timbuktu, you know they will fit on your printed circuit board. These are all metric countries. You have no guarantee if you order American electronic surface mount parts, that they will fit.

The situation is actually far worse than explained thus far. In the United States, our PCB software puts down design grids in mils (a feral unit of the inch which is equal to one-thousandth of an inch) or in other words inches. The world standard for parts is metric. The standard grid size for which these parts are designed is 0.05mm, so there is no reason to expect the metric parts to fit nicely on an inch based software grid. They are two different measurement units! Recall the surface mount parts may have been named in terms of inches, but they are actually designed to fit on a metric grid and are metric parts. The software used to connect up parts makes many mistakes in a mixed US/metric environment. Often manufacturers have to fix these "by hand." There is no guarantee of compliance to layout standards when metric and Olde English are mixed. Metaphorically, we are trying to fit square pegs into a set of round holes. Metric parts on a metric grid are interconnected by software to international standards, US parts which are metric on a non-metric grid are not.

To this day, should you decide to purchase shoes in the United States, the base unit used to measure your feet is the *barleycorn*. The largest shoe size is 13 with sizes counted backwards in barleycorn units (three barleycorn to an inch). A metric based shoe size standard exists, called *mondopoint*. Mondopoint is measured in millimeters along and across the foot. NATO uses this standard as does most of Asia. Expensive shoes such as ski boots use mondopoint to make certain of a good fit to a person's foot.

The metric system is but a subset of a larger set of useful and streamlined international standards. Countries around the world have met and worked out numerous standards. One of these standards is paper size. A series (ISO 216) paper is used by all countries, with the exception of the United States and Canada. This is why, when a photocopier or printer's paper cassette is empty, quite often it will say "load A4 paper" in the US. It is the international paper default size.

At first glance the size of A4 paper might seem odd. It is 210 mm x 297 mm. Despite appearing to offer odd linear values for paper when first encountered, these values have been chosen very carefully.

The standard American paper sizes are: 8.5" x 11", 11" x 17", 17" x 22", and 22" x 34". The "approximately equivalent" A-series "metric paper" sizes are: 210 mm x 297 mm, 297 mm x 420 mm, 420 mm x 594 mm and 594 mm x 841 mm. So why would the world choose these strange sizes over the nice monotonic values of American paper? It all comes down to what happens as one doubles each size in one direction only, as both of these paper sizes do. In Figure 12.1 American paper sizes and "Metric Paper" sizes, are placed side by side, and each formed into

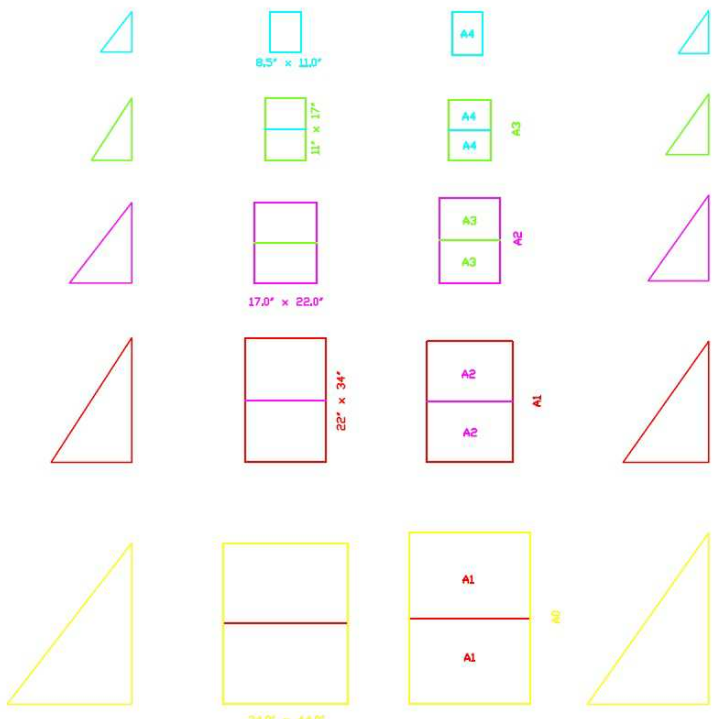

Figure 12.1: US and A series paper sizes cut into triangles and then mirrored into sheets. The US paper triangles are on the left and A series paper triangles are on the right

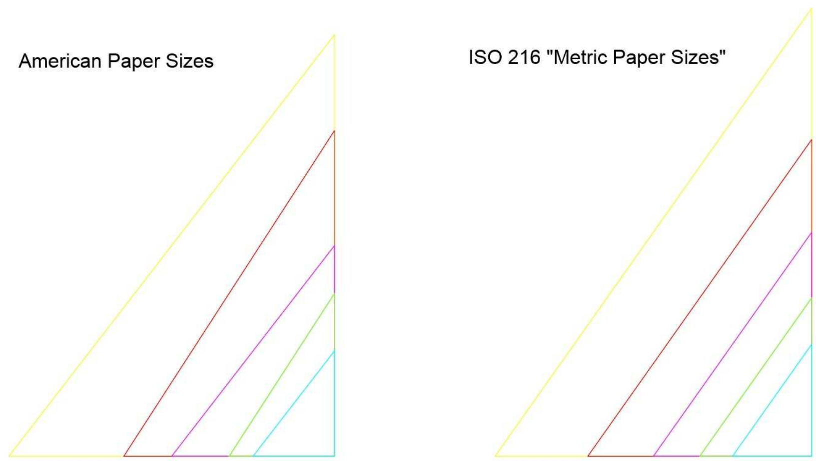

Figure 12.2: US and A paper sizes cut into triangles and then mirrored into sheets.

a triangle. This is equivalent to cutting a sheet along its diagonal, and producing a triangle with exactly half the original area. If one mirrors the triangle about its hypotenuse, then it produces the rectangular paper from which it was originally derived.

You might not notice a difference at this point. The way to clearly see a difference is to place all the colored triangles for each paper size with a common shared point at the vertex of their right angle, which is done in Figure 12.2

It should be immediately obvious, that the hypotenuses of the A-Series "metric paper" are all parallel, and the American sizes are not. What does this mean? It means that the aspect ratios of the "metric paper" are all identical. They are all equal to the square root of two. If you take 297 mm divided by 210 mm you will obtain 1.414 which is the square root of two. The American paper aspect ratios oscillate back-and-forth between 1.2941 and 1.5455.

Why is the aspect ratio important? Well, if the paper aspect ratio is the same, then one can enlarge A4 paper to A3 exactly, and from A3 to A2 exactly. The lengths of the two legs of the "metric paper" triangles can both altered by the same amount to fit into the next sized triangle. This is not the case for American paper. One cannot exactly fit an 8.5" x 11" image onto 11" x 17". One can fit every other size however, so

8.5” x 11” will fit onto 17” x 22” or 34” x 44” and 11” x 17” will fit onto 22” x 34” but they will not map onto each other without distortion or paper waste.

If one has an engineering drawing, or any drawing, or advertisement for that matter, which is size A4, it can be exactly doubled to A3 perfectly on a printer or plotter. One could double its size again from A3 to A2, and it would still fit perfectly without distorting the dimensions, or producing waste.

A4 paper and notebook binders are not available in US office supply stores. The use of A4 paper in the US is generally not discussed, possibly because the majority of US citizens have no idea what it is, or why the rest of the world uses it. As stated previously, Ronald Reagan made the executive choice to change government paper from 8 1/2” x 10 1/2” to 8 1/2” x 11” in the 1980s. It is unknown if A4 was even a consideration in this decision.

Another change which would bring more order to everyday life would be the introduction of the international date format (ISO 8601). This format is YYYY-MM-DD or year first with a dash, month next with a dash and then the day. In each case there are to be two digits even if they are leading zeros. So the founding of the US was on 1776-07-04. The Gettysburg Address was given on 1863-11-19 and Pearl Harbor was attacked on 1941-12-07.

This format brings order to a date scheme, which while accepted and taught in the US, is not consistent with the number system we use. If one sees any number, say 4321, we know the digit furthest to the left, 4, represents the largest value of the number or 4,000. The next column is hundreds, tens and ones. This is ubiquitously taught in public schools. The left-most number is the largest, and as one moves to the right, each place represents a smaller value. In the US, the founding date of the United States is proverbially written 7/4/1776. One cannot use the common 7/4/76 because this is ambiguous, the year could be 1776, 1876, or 1976. The first value is the month, which is not the largest value. The smallest value is next, followed by the largest. This is not even consistent with the common grouping of US units from largest to smallest. If I said that a distance was 2 feet 5 inches 6 yards, I’m sure you would think why didn’t he say 6 yards, 2 feet and 5 inches? That would be the expected descending grouping.

A most important application of this international date standard is with computers. When using this standard, dates will automatically sort in order. One can develop file names which will automatically sort by date. For example, a general name of a file could be:

Title which is constant YYYY-MM-DD **Changeable suffix**

An example of a newspaper article named so that it will immediately sort by newspaper name and date is:

Des Moines Register 1975-08-23 Islands in a Metric World.pdf

The first title is the name of the newspaper, *The Des Moines Register*. Next is the international date. Finally the changeable suffix is the title of the article which is *Islands in a Metric World*.

The standard is written to document both date and time. It turns out that one can also uniquely add on the time of day using a 24 hour clock. The format is: YYYY-MM-DD HH:MM:SS For instance, the Apollo 13 spacecraft was launched on 1970-04-11 13:13:00 CST

Microsoft Windows and Mac OS both allow for international date and time to be set and displayed. Even the smallest concessions to international standards like international date and time, A-series paper, or the metric system is not implemented in our government, industry or educational institutions. This lack of adoption not only separates us from the rest of the world, but also costs us greatly as a nation in many ways, even if the public is unaware of these standards.

Perhaps the most famous cookbook in America was Julia Child's *Mastering the Art of French Cooking*. It is not well known that Julia, who was from Pasadena California, did all of her cooking in metric because it was so much easier, and would then convert the recipes to US units.[1] Cookbook publishers realize that popular cookbooks cost more to produce because the US edition is in our US units, and if the book is to be sold in the UK, Australia, New Zealand, South Africa or other English speaking countries, the recipes must be converted to metric (SI) units. This is also true for American Cocktail Recipe Books which use ounces and jiggers rather than milliliters.[2]

Another difference between the US and metric countries is fuel efficiency computation. In the US, it has traditionally been expressed as miles per gallon or MPG exclusively. Europeans, and others in metric countries do not compute their fuel efficiency in Liters/Kilometer, but in Liters/ 100 Kilometers. Say a car gets about 30 miles to a US gallon, which is 7.84 Liters/100 Kilometers. The formula to convert is Liters/100 Km = 235.21/mpg. In Table 12.6 we have the two ways of expressing fuel efficiency side by side:

MPG	L/100 Km
10	23.52
15	15.68
20	11.76
25	9.41
30	7.84
35	6.72
40	5.88
45	5.22
50	4.70

Table 12.6: Miles Per Gallon expressed as liters per 100 kilometers

The liters per 100 Km values give a much better intuitive understanding of the actual fuel efficiency of a car. The fuel savings when one goes from 10-30 MPG show an obviously quick increase when we look at the expression in Liters/100 Km. After 30 MPG the fuel efficiency change is much slower. Another way to view this is by rewriting the table in terms of milliliters of fuel instead of liters.

MPG	mL/100 Km	Fuel Saved	500 mL Bottles
10	23 520	–	–
15	15 680	7 840 mL	15.68
20	11 760	3 920 mL	7.84
25	9 410	2 350 mL	4.70
30	7 840	1 570 mL	3.14
35	6 720	1 120 mL	2.24
40	5 880	840 mL	1.68
45	5 220	660 mL	1.32
50	4 700	520 mL	1.04

Table 12.7: Miles Per Gallon expressed as liters per 100 kilometers and the computed volume of fuel saved in milliliters

Table 12.7 compares miles per gallon, to mL per 100 Kilometers (which can be easily read as decimal liters: 23 520 mL = 23.520 L), the amount of fuel saved from the MPG improvement is next. The last column of Table 12.7 represents the number of 500 mL bottles of fuel saved. Bottled water in the US is sold in 500 mL sizes, and it is a familiar everyday touchstone for the amount of fuel saved.

If we doubled the mileage to 100 MPG we obtain 2352 mL/100 km, and save a fuel volume of 2348 mL when compared with 50 MPG. The difference in fuel efficiency gain from 50-100 MPG is close to the difference from 20-25 MPG.

In almost every area of life, the rest of the world has evaluated how it implemented its measures, and then reformed them. In the United States, the 18th century status quo continues to rule. The gallon we use to compute gas mileage, is the wine gallon, which dates back to 14th century in England. A ten penny nail designates not a nail dimension, but the price of them in England long, long ago. It is not hard to understand why it takes more energy to create products in the US, than it does in Europe—we have no idea how to measure.

References

[1] Pomroy, Wendy *Metric Today* Vol. 44, No. 2 March–April 2009 page 3

[2] Regan, Gary *SF Gate (San Francisco Chronicle)* “A bartender’s plea for presidential metrics” March 1, 2009 page E-6