**Chris Wolff** **February 2005**
**Subject:** The Measure of All Things or An Ode to the Metre
**keywords:** Measure, Metre, Standardisation

# The Measure of all Things or An Ode to the Metre

## 1 Chaos in the units: The need for standardisation

For a better understanding of the need for a revolution in the system of units and measures at the end of the 18-th century the table shows you an example of the chaos as it existed at that time in Europe. It presents as an example a number of length measures as in use

**In the Netherlands**
All towns and regions had their own feet and related units.
The *roede* (*rod* in English) was a number of feet, that depending on where you were could be 10, 12, 13, 14, 20 or 21 feet. Most feet were divided in 12 *duimen* (*inches*) apart from the *Amsterdamse voet* which was relatively short and divided in only 11 *duim*.
In the beginning of the 19-th century the *Rijnlandse roede* became the *primus inter pares* in the Netherlands and was defined in six decimals relative to the meter. At the side of the townhall of Leiden near a stair, this standard was made available to the public by two large bolds.
This example is only for length units, but there are also area, volume and weight units, each with their own chaos.

Table with an example of *Roedes, voeten, duimen* and *lijnen* (and *punten*)

| | m/roede | voet/roede | mm/voet | duim/voet | lijn/duim |
|---|---|---|---|---|---|
| Rijnlandse roede Nederlands 1806 | 3,767358 | 12 | 313,9465 | 12 | 12 |
| Rijnlandse roede Pruisisch 1816 | 3,766242 | 12 | 313,8535 | | |
| Kasselrij Kortrijk kleine roede | 2,976 | 10 | 297,6 | | |
| Rotterdamse roede | 3,767 | 12 | 313,9 | 12 | 12 |
| Amsterdamse roede | 3,68 | 13 | 283,1 | 11 | |
| Drentse roede | 4,12 | 14 | 294,3 | | |
| Uitgeestse roede | 4,16 | 14 | 297,1 | | |
| Kasselrij Veurnese roede | 3,892 | 14 | 278,0 | | |
| Antwerpse roede | 5,74 | 20 | 287,0 | | |
| Kasselrij Kortrijk grote roede | 5,952 | 20 | 297,6 | | |
| Kasselrij Oudenaarde | | 21 | | | |
| Brussels (andere bron) | 5,68 | ongeveer 20 | 279 | | |
| Gelderse roede | 3,8 | | | | |
| Sallandse roede | 4,53 | | | | |
| Blooise roede | 3,617 | | | | |
| Schouwse roede | 3,727 | | | | |
| Duivenlandse roede | 3,667 | | | | |
| Brusselse roede | 5,8 | | | | |

**In France**
The situation in France was not different from that and probably worse. In France there was no standardisation and as late as 1788 **Arthur Young** wrote in *Travels during the years 1787, 1788, 1789* published in 1793:
"In France the infinite perplexity of the measures exceeds all comprehension. They differ not only in every province, but in every district and almost every town".
In fact it has been estimated that France had about 800 different names for measures at this time, and taking into account their different values in different towns, around 250,000 differently sized units. This means on average 300 sizes per unit name.
Some units had different sizes for buying or selling. The difference was the authorised profit margin for the trader.
At the end of the 18-th century, also in France, people started to feel that this chaos in measures and units was holding back the

economy and it created the climate in which people were prepared to change their habits and adopt new units. But this went not whole-heartily as we will see.

## 2 The decimal drive: The need for rationalisation

There was a second drive for introducing a new system of units and measures.
In Leiden in 1585 **Simon Stevin** (Brugge 1548 till 1620 Leiden or The Hague) had already published his booklet *De Thiende*, in which he taught to a large public how easy calculation is when carried out in a decimal system. This booklet was translated in French (by Stevin himself), English and Danish and had a great influence in Europe. Apparently it took about 200 years and a revolutionary environment before decimal fractions would become the standard in measurement units and money.
Stevin was also very important for the academic development of the Netherlands, as he was the first to give his science lectures in Dutch. Before him al lectures were given in Latin. It was of great political an economic importance that science was taught in vernacular, since it opened the world of science to all these craftsmen and engineers that did not have a classical education. We owe to Stevin many Dutch scientific words that have only a latin equivalent in the languages around us, such as *wiskunde*, that he called *wiskonst*. Stevin had to invent all kinds of translations. Two of the most beautiful ones, that we lost in the meantime, are *spiegheling ende daet* for *theory and practice*.
The United States were the first country to introduce decimal money in 1792. Decimal money was introduced in France during the Revolution (approx 1793, another source says 1799). Before that one had 1 Livre = 20 sous and 1 sous = 12 denier, identical to the British system in use until approximately 1970, which by the way used the French symbols £'s and d, for pounds, shillings and pence. The Livre was replaced by the Franc (approximately worth 1 Livre), and was divided in 10 decimes and 100 centimes.
Everything had to become decimal. The repetition circles of Mechain and Delambre (see further) were in 400 grades (=360 degrees). Alder says that using 400 grades in a circle happened sometimes during the years 1793 till 1798. After that period it happened as well.

## 3 The Revolutionary environment

In the second half of the Middle Ages the English king had managed to standardise the units in his country. Unlike in England, the French kings had never succeeded in doing the same in their country. The local powers and nobility apparently were too strong. So it is not surprising that the introduction of the new system of units coincides with the Revolution. One usually takes as the start date of the Revolution 1791 May 5 when king **Louis XVI** was forced to call the parliament together, something that had not happened in about 170 years. In January 1793 the king was executed under the guillotine
The political climate was such that one was not satisfied with just standardisation of units. One had great ideals. The new units should be truly universal, i.e. not dependent on something national. In addition the new system had to be rational i.e. all units (length area, volume and mass) had to be based on a single length measure and have decimal subdivisions.
Also the time and calendar had to be decimal. From 1793 until 1806 a decimal calendar and decimal clock were the only official time measures in France. A day was divided in 10 decimal hours. Each such hour was divided in 100 decimal minutes. In SI nomenclature we would now call such an hour a deciday (dd) and such a minute a milliday (md). There were even made decimal clocks, but there was not much interest by the public. The decimal calendar consisted of 12 months of 30 days. Each month divided in three ten day periods called decades. This calendar was a direct rebellion against the church, since it abolished the 7 day week and therefore undermined the obligation for the people to attend mass every Sunday. In addition as a consequence the whole Christian calendar was abolished as e.g. Easter or Pentecost would no longer fall on the rest day (the tenth day of the decade). Note that Christmas on the contrary fell every year on the same day of the decade: the fourth day (Quartidi) of the month Nivôse. After one and a half year the obligation to display the new calendar was already withdrawn. And in 1806 it was officially abolished.
Some sources state that Napoleon abolished the revolutionary calendar as a trade off with the Roman church for their recognition of him as emperor of France.

## 4 'Design' of the meter as the standard

The new measure had to be universal and of all people. This was both an idealistic requirement in line with the ideals of the Revolution and a practical requirement, since it had to be acceptable to all countries of the world.

Therefore promoting one or the other Paris measure to become the standard was not enough. No, the new standard should be based on some quantity of nature.

In 1790 **De Talleyrand** presented to the *Assemblée Nationale* a proposal due to Condorcet to use a system based on one length standard, with decimal multiples and subdivisions and all measures of area, volume and weight would be derived from that. As the length unit he proposed the length of a one second pendulum i.e. a pendulum that beats with half a period equal to one second as the world standard. Clockmakers call *half a period* one stroke. This would result in a standard of about 992 mm long. This proposal was accepted. Unfortunately the length of a one second pendulum varies with the gravitational acceleration, which varies from the equator to the poles. More specifically such a pendulum is 0,27% shorter at the equator and 0,27% longer at the poles. Hence one had to find international agreement on the latitude at which the new standard was to be defined and measured. One failed to achieve this. The French proposed to take the average latitude of 45 degrees, which sounds reasonable, but this was unacceptable for the English who have no part of their country that is on that latitude. Also the USA and Germany could not agree to the 45 degrees standard latitude.

As an alternative, in 1791 **Borda** proposed to base the length unit on the length of the meridian from equator to pole and define de new standard as 1/10,000,000 of that arc. This arc should be measured by triangulation of the distance between Dunkerque and Barcelona. It is obvious that this would not be internationally acceptable either, since this is even more specifically French than a 45 degree latitude, but the proposal was accepted in France anyway. So an expedition was planned to measure this distance.

Note that already in 1670 **Gabriel Mouton** had proposed to use as a standard of length; the length of 1 arc minute of the meridian. This is in practice the length of a nautical mile. The advantage of this definition would have been that the new measure would then be used both on land and at sea. Something we have not achieved with the meter, since the nautical mile is still the unit at sea.

It may be that **Borda** had hoped that his definition would become the standard also at sea, because he advocated the use of a circle divided in 400 grads, each grad divided in decimal subdivisions. If longitude and latitude are expressed in grads, with decimal subdivisions, the kilometre would correspond to an arc of exactly 0.01 grad.

In such a coordinate system the decimal hour would correspond with 40 grads longitude. A 24 hour day does not fit in this system. Hence the digital new length standard (the name meter is not yet given), the 400 decimal grads in a circle and the decimal clock form a coherent system. A very ambitious system though, that could only be designed in a revolutionary era.

The distance from the equator to the pole had be determined by measurement of a part of the Paris meridian and extrapolation to the total length. The measurement method for this was by triangulation. This method was applied for the first time in 1615 by **Willibrord Snel van Rojen** (**Snellius**). He measured the distance between Alkmaar and Bergen op Zoom and published the result in 1617 under the title *Erathostenes Batavus, De terrae ambitus vera quantitate*. His estimation of the distance from equator to North pole was (only) 3.5% short.

## 5 The expedition

The expedition started in 1792 and was completed in 1799. The new measurement had to be far more accurate than the work by Snellius. The new target accuracy was about 10^-5. They achieved eventually 10^-4 or 0.1 mm on 1 meter. In the formula in Fig 5.3 one can easily see that the most error sensitive part of the measurement of the Earth quadrant is the difference in the latitudes of the end points. In the case of Snellius this was only 1 degree. By now using the distance from Dunquerque to Barcelona, which covers about 10 degrees (1150 km) an order of magnitude better accuracy would be achievable.

The second basis for increased accuracy was in the use of a novel instrument for measuring angles, the Borda repetition circle. The trick of the repetition circle is that an arc between two objects e.g. the horizon and a star or between two church towers, was measured repetitively and cumulatively before the cumulative angle was read on the circular scale. This about 2 m high instrument had to be carried to the top of all church towers of the network via usually very narrow turning staircases. Méchain, one of the two scientist going to execute the work, claimed that with the repetition circle he could close the triangles to an accuracy of 3.5 arc seconds (on 180 degrees), which implies an accuracy of 5*10^-6, or 5 cm on 10 km. This shows the original ambition level of the expedition, which was apparently to achieve an accuracy for the meter of about 5 micrometer.

The two scientists carrying out the work were Delambre and Méchain. Delambre started at Dunkerque and worked southwards, whilst Méchain started at Barcelona. They expected to meet each other at Rodez. Hence 30% of the strech was for Méchain and 70% for Delambre. The Southern part of the stretch was much more difficult to do than the relatively flat Northern part. It is impossible to summarise the difficulties they encountered during their work. However one exception is made: the tragedy of Méchain.

There was a fundamental difference in the working method of the two scientists. Delambre noted all observations made in a logbook and he reported the results of his calculations in a separate book. Whereas Méchain first filtered his observations and only those that he considered reliable or correct were noted in his logbook. This eventually resulted in a serious problem. When measuring the latitude of the reference point in Barcelona he discarded quite a number of observations because he assumed that he had made errors. Many months or perhaps years later he realised that probably his measurements were right but that his filter was wrong. His filter was based on assumptions about the shape of the Earth hence the curvature of the meridian. By the time he began to understand that his assumptions were wrong and his measurements had probably been OK, he could no longer repeat them, because Spain and France were then at war and Barcelona was not accessible for him. He understood the consequence of this error very well: They would produce an incorrect length for the meter, so it undermined the whole objective of the expedition. As a consequence he suffered from serious mental problems and this resulted in lack of progress with the work. Whilst Delambre had completed his stretch in less then two years it took Méchain about 7 years to complete his part. On top of that as a result of his error the meter became actually 0.2 mm too short. (or 200*10^-6). This is a factor 40 times the initial target accuracy of 5*10^-6. Delambre must have understood what had happened, since he kept the evidence for the error separate from the official recordings of the expedition.

An essential component of the expedition was the measurement of the baselines, one for each of the scientists. One was in the North part near Melun and the other in the South part near Perpignan. These baselines were along a straight stretch of road of approximately 10 km long. The target accuracy of 5*10^-6 implied that these stretches had to be measured to an accuracy of 5 cm. For this work they used each four platinum rulers of about 3,60 m long. These four were laid in a line and then the first one was taken up and moved to the other end, then the second and so on. It took them 41 days to measure the 10 km base line near Melun. Bear in mind that a sand grain of 0,5 mm would already represent an error of 140* 10^-6 on the length of one ruler. Which is too big.

In 1799 the work was finally completed and the meter officially defined. The official meter was 0,325 mm shorter than the provisional meter of 1793. From the modern, very accurate measurements of the quadrant of the Earth, we now know that whilst the provisional meter was 0,096 mm long, the final meter was 0,229 mm short. As said above, this is the great tragedy of Méchain. The seven years of work of Méchain had only contributed inaccuracy.

Delambre published all the results of the expedition in 1806 in the *Base du système métrique décimal*. Napoleon wrote the following comment in this report, when it was shown to him: *Les conquêtes passent, et ces opérations restent*.

The new meter standard was eventually fixed as a platinum rod of 1 meter long between the two flat ends. This standard was kept in Paris and all countries subscribing to the standard received a copy.

## 6 The introduction of the standard in the world

In May 1812, just before he left Paris for his campaign into Russia, Napoleon abolished the new metric measurement system. The traditional forces against it had appeared too strong. All the work seemed to have been in vain.
However the chaos in measures had not only existed in France, and in 1820 King William I approved the law introducing the new metric system of units in the Netherlands, which in those days comprised what is now called the Benelux. In 1830, when Belgium became independent, one of the first things the country did was to subscribe officially to the new system as well.
It took until 1840 before France re-introduced the metric system. Gradually more countries followed. It is also worth noting that in 1866 the United States of America accepted the metric system as a legal measurement system, but they failed to make it obligatory.

Three more events in the development of the metre have to mentioned.

Just after the second world war, the US Department of Defence, introduces a world wide coordinate system that is based on the meter: The Universal Transverse Mercator (UTM) system, known by everyone owning a Global Position System device (GPS). In this system, every location on Earth, be it on land or at sea (!), is given metric coordinates in a rectangular metric grid. In the usual Mercator projection the globe is projected on a vertical cylinder. This works fine on the Equator but gives increasing distortion for increasing latitudes. In a Transverse Mercator projection the cylinder is horizontal and has one meridian in common with the globe. The *Universal Transverse Mercator system* (UTM) uses 36 of these horizontal cylinders, with central meridians each 6 degrees longitude apart. The distance from the Equator to the poles is divided in 10000 km blocks. The importance of the UTM system in the context of the history of the meter is that it is an important application that comes closer than anything else to the philosophy behind the original definition of the meter.

In the course of time, the accuracy of the meter based on a reference specimen held in Paris becomes insufficient. Therefore in 1960 the 7-th CGPM (Commission Generale des Poids et Mesures) defined ***the meter as the length equal to 1 650 763,73 wavelength in vacuum of the radiation corresponding to the transition between the levels 2p10 and 5d5 of the krypton 86 atom***. The accuracy of the meter is then about 4 * 10^-9. The beauty being that this could be measured anywhere in the world. Completely in line with the original philosophy, that the unit should be truly universal.

Technology progresses further and an even more accurate definition is required.
In 1983 the 17-th CGPM redefines the meter in terms of the speed of light in vacuum: ***the meter is the distance that light travels in 1/ 299 792 458 second***. Since then the meter has become dependent on the second. Note that with this definition in place it is no longer possible to measure the speed of light. If one measures the time it takes for light to travel from point A to point B, all one does is measuring the distance between the points.

## 7 Status of implementation of SI

It has been some 200 years ago now, that the metric system was introduced. There are still quite some relics around and in use of the old units. For example, the butcher is not allowed to announce the price of his meat per pound, so he gives it per 500 gramme. The customers don't have this legal restriction and they happily order half a pound of something and the butcher knows that they mean 250 gramme. This is the case in The Netherlands (*een pond*) and France (*une livre*). However in Italy it is not customary to use the *lira* for mass.

The most recent purification of our measurement units was per January 1, 1978, when in many EU countries a number of old units were prohibited. This has not been very successful. The calorie was supposed to be banned and the megajoule (MJ) to be used instead. The same story applies for the horsepower (hp, pk in Dutch). The power of car engines should be quoted in kilowatt (kW) but car salesmen prefer the larger number in kW over the number in kW. It is strange that they don't get a penalty like the butchers for the use of illegal units. Doctors have an official exemption to measure blood pressure in mm mercury. Their argument was that the conversion would lead to confusion and unavoidably fatal incidents.

During holidays in France, you can note that locals order *un demi pression*, when ordering a glass of draught beer. They receive a normal glass of beer of between 20 or 30 cl.  One wonders if this is a half, what then is a whole? The first thought is, that a whole would be a pint, but that proved to be wrong. It appeared that *un demi* stands for *un demi-sétier*. Whilst *un sétier* equals  *une chopine*, and both equal half *une pinte*. One should know that a French pinte was approximately 0.96 litre and therefore much bigger than an English pint, which is closer to half a litre. It is also worth mentioning that around the year 1800, for a while the name *pinte* has been the official name for the litre. So the old name was kept and the associated quantity slightly adjusted, like with the *livre*.

Carpenters in the Netherlands refer to the construction beams they use as *2 by 4* or *3 by 6*, when they mean 5 by 10 cm or 7,5 by 15 cm. Clearly the *duim* is still the underlying unit.

The EU supported drive to purify the unit system and use only SI units (*Système Internationale*) was very strong but has faded away. This is very disappointing. However on the long term there is hope. It is for sure that the SI system will last longer than e.g the oil industry. So eventually the barrels and standard cubic feet will vanish. One sees already that new topics are dealt with in SI units. Quantities of $CO^2$ emitted or sequestered are quoted in the metric unit *tonne* equal to 1000 kg, also in the conservative oil industry and together with gas quantities in cubic feet.

The conversion power of the computer has more or less undermined the drive to rationalise the system of units. Because of the computer, the need for mental conversions of quantities has reduced and so the need for decimal relationships between units.

The computer is also a great obstacle for standardisation. Continental Europe quotes a date as 26 May 2004 as 26-05-2004, whereas the US reverses the days and months and writes 5-26-2004. This can lead to expensive mistakes. There is an

ISO standard which resolves the confusion. It prescribes the format 2004-05-26.
Unfortunately this ISO format is not supported by Microsoft. Programmes like MS Excel and MS word don't recognise or allow these date formats. Hence it is almost impossible for people to adhere to the ISO standard.

A problems in the oil industry is the abbreviation for 1000 $m^3$ or 1 million $m^3$. People use all kinds of funny abbreviations such as $MMM^3$ or MMCUM or $Mm^3$. However, the correct SI unit for 1 million $m^3$ is $hm^3$ (hectometre cubed) and for 1000 $m^3$ it is 1 $dam^3$ (*decametre cubed*). Everybody is accustomed to the use of $cm^3$ or $dm^3$ and has been taught at primary school that 1 $cm^3 = (0,01)^3 = 10^{-6}$ $m^3$. The same rules apply for hm3 = (100 m)$^3$ = 106 $m^3$. It is questionable if reports using $hm^3$ are understand by the readers.

## 8 Bibliography

Ken Alder, The Measure of All Things (2002) ISBN 90 414 0569 0
History of measurement by J.J.O'Connor and E.F.Robertson
http://www-history.mcs.st-and.ac.uk/~history/HistTopics/Measurement.html#s25
History of Decimals and the Metric System, University of Melbourne (Aus)
http://extranet.edfac.unimelb.edu.au/DSME/decimals/SLIMversion/backinfo/metric.htm
Entry to biography and works of Simon Stevin:
http://home.wxs.nl/~hopfam/Stevin.html
J.T. de Vreese and G. vanden Berghe, Wonder en is gheen wonder, De geniale wereld van Simon Stevin. (2003) ISBN 90-5826-174-3

---

**Otto van Poelje** **February 2005**
**Report:** The 'KRING' on the Collectors Fair, Eindhoven

### De KRING op de Verzamelbeurs te Eindhoven

Enkele weken terug, op 12 en 13 februari, stond de Kring met een eigen tafel op de jaarlijkse Collectors Fair in het Beursgebouw te Eindhoven. Dit is de beurs waar IJzebrand vele jaren zijn eigen stand heeft gehad, en waar hij vorig jaar is uitgeroepen tot ***Verzamelaar van Het Jaar***. Nog steeds vragen bezoekers naar de ingenieur uit Odijk.
Wij (Leo, Jac, Jo en ik) stonden voor de Kring op het balkon, temidden van pure verzamelaars en verzamelaars-verenigingen. Rond ons stonden uilen, oude pijpen, balpennen en fluiten, geflankeerd door devotionalia, wereldbollen, sprinkler nozzles en een brandalarm dat elk kwartier werd geactiveerd.
Toch was dit geen verkeerde plek: de buren waren allen bijzonder aardige mensen, en het bleek dat de bezoekers in onze ruime gangpaden rust kwamen zoeken na het jagen op koopjes in de grote hal beneden. Dus kwam het heel vaak tot gesprekken met voorbijgangers, zelfs meer dan in andere beurzen waar we hebben gestaan. We hebben zelfs drie kandidaatleden gewonnen.
Op het andere balkon werd de nieuwe 'Verzamelaar van het Jaar' verkozen: zijn onderwerp was oude schrijfmachines, in een zeer smaakvolle stand.
Dit was een beurs, die zeker een herhaling waard is, volgend jaar.

*Promotie van onze* KRING

**Andere beurs: Verzamelaarsbeurs Utrecht**
De andere beurs waar de Kring dit jaar wil gaan staan, is de Verzamelaarsjaarbeurs in Utrecht, en wel op de zondag, 20 november 2005.
We kunnen dan de stand van Huib op die ene dag overnemen om de kosten te delen.

**Nog meer beurzen**
Op onze website www.rekenlinialen.org, onder het hoofdstuk 'agenda', staat een overzicht van andere interessante verzamelbeurzen.
Let vooral ook op de nieuwe verzamelbeurs in de AHOY-hallen in Rotterdam.