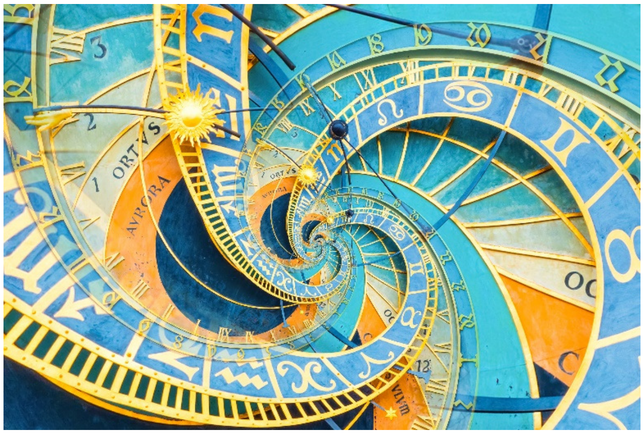
Measuring time

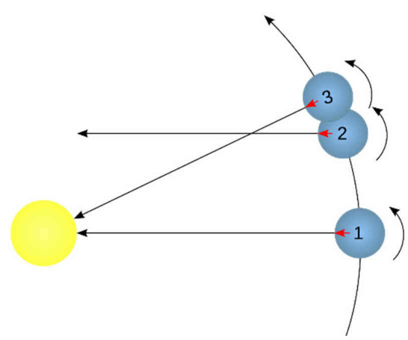


Accurately measuring time is an important underpinning of many aspects of project management, you need to know how long an should take to perform (or actually took) to determine its cost for use processes such as cost accounting, cost engineering, activity-based costing (ABC)[1], estimating, work study and incentive payment systems[2], as well as for developing and updating the schedule. However, while the ability to accurately measure time has been an accepted norm in business and social life for more than 100 years, but this was not always the case and the introduction of accurate clocks was one of the key enablers required for the development of modern management in the 19th and 20th centuries.

Developments in the measurement of time are closely linked to both the development of civilization and the development of the modern calendar. As civilization progressed and the world became more complex, the accurate measurement of time became both more important and more democratic. The availability of clocks shifting the measurement of time from a capability only accessible to the elite to something used by almost everyone, every day.

This article looks at the complexities of measuring time, and the development of devices from sun dials and water clocks through to modern atomic clocks. These developments occurred in parallel with, and were in part driven by, the development of calendars and astronomy[3].

The knowledge of ancient civilizations



The need to accurately measure the time within each day on a consistent basis was originally driven by the needs of astronomers as they attempted to calculate the movement of the earth and the heavenly bodies and to understand the various cycles within the lunar and solar years, to create accurate calendars.

This process was far from simple! There are three types of solar time reckoning based on astronomical observations: apparent solar time, mean solar time, and sidereal time, which is based on the

[1] For more on the ***history of cost controls*** see: https://mosaicprojects.com.au/PMKI-ZSY-020.php#Process1

[2] For more on the ***history of incentive payments*** see: https://mosaicprojects.com.au/Mag_Articles/SA1066_Incentivation_and_Performance.pdf

[3] For more on the development of calendars, download ***The origins of the Coordinated Universal Time (UTC) calendar*** from: https://mosaicprojects.com.au/PDF_Papers/P185-The_origin_of_calendars.pdf

apparent motions of stars other than the Sun. The sidereal day is shorter than the solar day. At time 1 in the diagram above, the Sun and a certain distant star are both directly overhead. At time 2, the planet has rotated 360° and the distant star is overhead again (1→2 = one sidereal day). But it is not until a little later, at time 3, that the Sun is overhead again (1→3 = one solar day). More simply, 1-2 is a complete rotation of the Earth, but because the revolution around the Sun affects the angle at which the Sun is seen from the Earth, 1-3 is how long it takes noon to return.

Add to this the fact the length of a solar day varies through the year, caused by the eccentricity of Earth's orbit, the Earth moves faster when it is nearest the Sun and slower when it is farthest from the Sun, and the 'wobble' in the tilt of the Earth's axis. For modern timekeeping, these differences are averaged out to create the mean solar day. The challenges faced by early astronomers in making these assessments were compounded by their operating assumption that the sun and stars orbited the earth[4], making the need for accurate time measurements essential.

The extent of the Ancient Greek astronomical knowledge can be appreciated from the Antikythera mechanism, an Ancient Greek hand-powered mechanical model of the Solar System. This device was built to illustrate, or predict, the relative positions and motions of the planets and moons, and demonstrates the level of knowledge in the 2nd century BCE. The mechanism predicts the 76-year Callippic cycle (that aligns the lunar and solar years) using a value of 27,758 days, while the modern value is 27,758.8 days. Similarly, it sets the Exeligmos cycle that predicts the recurrence of an eclipse of the sun in a particular geographic region as 19,756 days; the modern value is 19755.96 days. It also calculates more mundane things like the timing of Olympic Games (every four years) and the phases of the moon.

The value of being able to define and measure time was not lost on secular and religious authorities and the development and use of various time measuring devices gradually spread across all aspects of life. Some of the tools used include what are now considered 'ancient monuments' such a Stone Henge. These were built to determine key events such as the midsummer or midwinter solstice, as well as time measuring systems including graduated candles, sundials, water clocks, sand-glass/ hourglass, and much later mechanical clocks. But through to the 19th century it was still necessary to use astronomical observations to accurately set the time of noon on the clocks in any given locality.

Sundials and Water Clocks

Sometime before 3000 BCE Egyptians, Babylonians, and other ancient civilizations in China, the Indus Valley, and the fertile crescent, begin to measure time using sundials and water clocks.

Shadow clocks

Ancient Egyptian Obelisks, constructed about 3500 B.C were probably the oldest shadow clock used to measure time. The shadow moving to different marks on the ground enabled the Egyptians to calculate time and to divide day into parts. A few centuries later, custom designed sundials started to be used.

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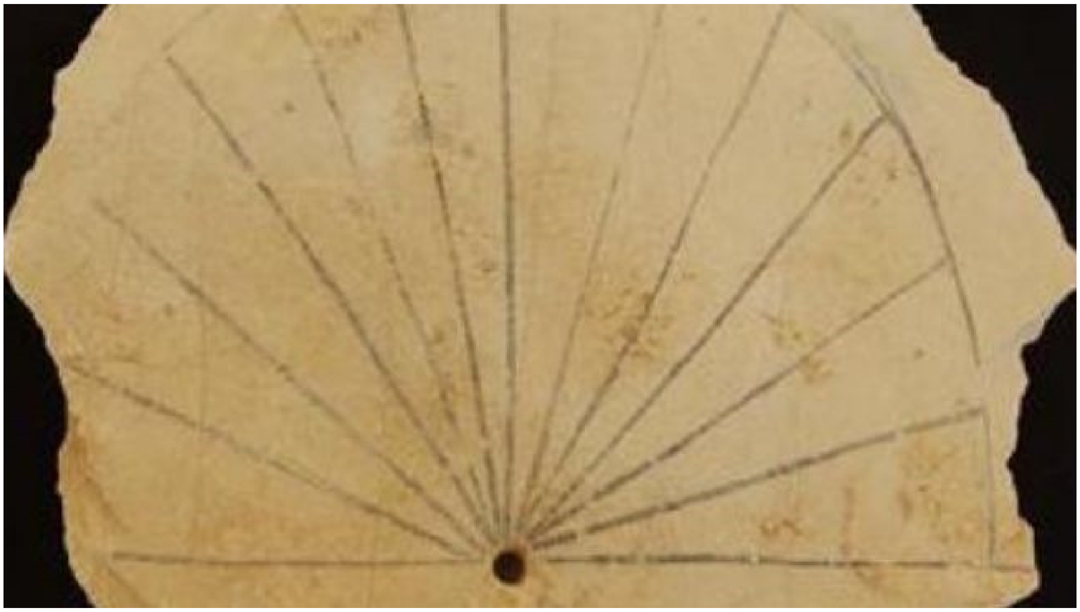
4 The assumption the sun and planets orbited the earth was not seriously challenged until the work of Nicolaus Copernicus in the 16th century, ***Project Management - A Historical Timeline***: https://mosaicprojects.com.au/PDF_Papers/P212_Historical_Timeline.pdf



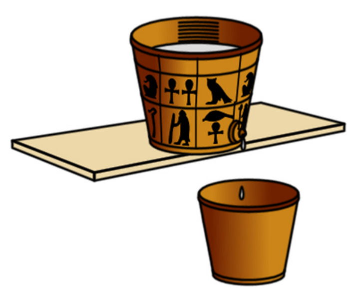
One of the world's earliest sundials dated c 1,500 BCE, excavated from the Kings' Valley, Upper Egypt

The Egyptians settled on the concept of a 12-hour day and 12-hour night. However, in the Egyptian system, the lengths of the day-time and night-time hours were defined by the movement of the sun, meaning night-hours and day-hours were usually a different length, and varied with the seasons. This variability in the length of each hour measured using a sundial created challenges comparing a time difference on different days throughout the year.

There is only one point on a sundial that is constant throughout the year, and that's noon, this does not change, but sunrise and sunset will. And, noon is easy to find, the sun is directly overhead (or at its highest point). Over time noon became the starting point for counting numerical hours - the "meridian". AM and PM come from this starting point, they are abbreviations of the Latin for "Ante Meridiem" (before noon) and "Post Meridiem" (after noon). Mechanical clocks retained these conventions, they kept the 12-hour face (it was obvious when it was day or night), and were made it go "clockwise" to mimic the direction of the shadow on a sundial in the Norther hemisphere.

Water clocks

Water clocks are also known to have existed in Babylon, Egypt, and Persia around the 16th century BCE, and other regions of the world, including India and China, have evidence of water clocks that may pre-date those in the 'fertile crescent' by more than 1000 years.



Water clocks uses the flow of water to measure time, the amount flowing into (or out of) a container changes the level (or weight) and this change can be measured against a predetermined scale. Some of these devices were designed to measure the time of day (or night), often for the purpose of timing religious observances. Others simply measured a defined period of time. For example, the 4 hours of a night watch could be measured by adding a defined volume of water to a container with a small hole, once the water had drained out, the watchman could wake up the next watch keeper[5].

The complexity and accuracy of water clocks were progressively improved through to the time of the Byzantium Empire and the development of mechanical clocks. From earliest times, significant effort was made in the design of the water clocks to deal with the different length of the day (and corresponding different length of hours) throughout the year. In the medieval Islamic world (632-1280), water clocks built by the Arabic engineer Al-Jazari, are credited for going well beyond anything that had preceded them. In his 1206 treatise, he describes one of his water clocks, that recorded the passage of temporal hours, which meant that the rate of flow had to be changed daily to match the uneven length of days throughout the year (Illustration of the Elephant Clock from Al-Jazari's book.).

Ordinary people continued to use these seasonally varying hours until the advent of mechanical clocks in Europe in the 14th Century, made the more precise system we use today feasible.

Standardizing hours and minutes

The move to a standard hour of 60 minutes was proposed by Greek Astronomer Hipparchus to facilitate astronomical calculations sometime between between 147 and 127 BCE. He proposed dividing the day into 24 hours of equal length (which came to be known as equinoctial hours because they are based on 12 hours of daylight and 12 hours of darkness on the days of the Equinoxes). He also devised a system of longitude lines for mapping the earth that encompassed 360 degrees and that ran north to south, from pole to pole.

Some three hundred years later, in his treatise *Almagest* (circa A.D. 150), Claudius Ptolemy explained and expanded on Hipparchus' work by subdividing each of the 360 degrees of latitude and longitude into smaller segments. Each degree was divided into 60 parts, each of which was again subdivided into 60 smaller parts. The first division, *partes minutae primae*, or first minute, became known simply as the minute. The second segmentation, *partes minutae secundae*, or *second minute*, became known as the second.

The Ancient Greeks and Romans were fully aware the world was approximately spherical and that the sun appeared to circle the earth once every 24 hours, linking the concept of degrees, minutes, and seconds to the measurement of time. But minutes and seconds were not used for everyday timekeeping until many centuries after the *Almagest*. The primary reason for this appears to be the accuracy of the machines used to measure the passing of time. Only with the advent of mechanical clocks in Europe in the 14th Century, did the system we use today become commonly accepted.

[5] Other devices for measuring a set amount of time include graduated candles which as the candle burned down, lines marked the passing of each hour and the hour glass. Hour glasses could be manufactured to a high degree of accuracy and were used to measure time on sailing ships through to the development of the chronometer in 1761.

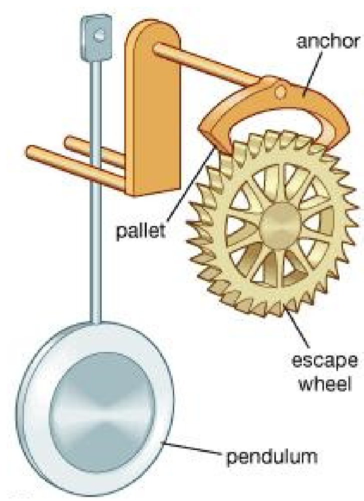
Mechanical clocks

The first clocks

Mechanical clocks began to replace water clocks in the 13th century. The key was the invention (or adaptation) of a clock escapement mechanism which regulated the amount of movement that occurred with each tick of the clock. The first of these appears to have been the verge (or crown wheel) escapement. There were several variations; in the *verge and foliot* escapement the moment of inertia of the foliot (a balance beam) controls the oscillation rate, another used a balance wheel. This mechanism was possibly invented around 1275. However, the oldest drawing of an escapement was by Jacopo Dondi dell'Orologio (1290–1359) in 1364.

The mechanical power source for the clocks was initially weights unwinding from a spool, and later some clocks used a spring. These early clocks had similar accuracy to the more advanced water clocks, at around +/- 15 minutes per day, but by not requiring a water supply were easier to build, locate, and maintain. Consequently, in the early-to-mid-14th century, large mechanical clocks began to appear in the towers of monasteries, cities, and other important locations, both as a mark of civic pride, but also to make the passage of time more important in daily affairs. Verge escapements were used in virtually all clocks and watches for the next 400 years.

The next major improvement in accuracy was the invention of the pendulum clock by Dutch mathematician, physicist and astronomer, Christiaan Huygens in 1657. The swing of a pendulum was far more precise and controllable making the mechanism more accurate. Huygens claimed his pendulum clocks had an accuracy of 10 seconds per day. Similar improvements occurred with the invention of the balance spring used in pocket watches. There is some dispute as to whether it was invented around 1660 by British physicist Robert Hooke or Dutch scientist Christiaan Huygens, with the likelihood being that Hooke first had the idea, but Huygens built the first functioning watch that used a balance spring.



This increase in accuracy in turn focused attention on the error caused by the verge escapement. The verge was replaced by the anchor escapement in pendulum clocks, probably invented around 1660 by Robert Hooke, and widely used beginning in 1680, and by other types of escapement in watches. Until this point, accurately measuring a second was extremely difficult (minute hands on clocks were not invented until the late 16th century, with second hands coming about 100 years later).

Applying time

For land-based use, pendulum clocks were the benchmark of accuracy through to the 20th century. The introduction of factories as part of the industrial revolution made time keeping clocking on and off and production rates important[6].

6 For more on the evolution of management (including Mill time) see ***P050 Origins of management*** at: https://mosaicprojects.com.au/PMKI-ZSY-005.php#Overview

One of the more interesting adaptations of this approach to time was the mill clock. The new system of cotton manufacturing changed the way work was organised. Winter or summer, rain or shine, the machines set the pace and the factory clock told workers when to work and when to rest, and mill workers toiled in time with their machines. Time was money and some manufacturers tried to control the time in their mills to increase productivity and profits.

This double dialled longcase clock was from Park Green Mill, Macclesfield, made by E. Hartley, Macclesfield, c. 1810[7]. The bottom face of the double dialled clock showed the real time. The top face showed *mill time*. Its hands were connected to the water wheel and like the mill's machines, they only moved when the water wheel turned. If the water wheel stopped or slowed down, so did *mill time*. Workers could only go home when *mill time* said so.

Until the advent of first railways and later the telegraph, each town and village set its own time based on the solar noon in its location. A local astronomer or other suitably trained person would use a sextant to determine midday and update the town clock. All the other clocks would then be set to the town time. This tradition continues with the firing of the noon gun or the dropping of a ball in many cities and harbours around the world.

However, intercity railways needed a common timetable across their network which led to standard times being introduced. Greenwich Mean Time (GMT), has been used in the UK since 1847 to standardise time across the country and facilitate railway timekeeping. Then international telegraph communication required the time at different locations around the world to be coordinated leading to the creation of UTC starting in 1884[8].

This ability to measure time relatively accurately underpinned the development of scientific management in the early part of the 20th century which in turn led to the development of modern project management[9].

The longitude problem

Pendulum clocks require a stable foundation - any movement makes their time keeping unreliable, which means you cannot use a pendulum clock on a ship. This caused a major problem and 1000s of shipwrecks.

The measurement of longitude (how far East or West you are of a given meridian) is important to both cartography and navigation. For safe ocean navigation, knowledge of your current latitude and longitude is required, together with an accurate chart (map). Latitude is relatively simple to calculate by measuring the height of the sun at noon, which in turn is the highest point the sun will reach above the horizon on that day (its maximum azimuth).

7 Image from: Science Museum Group. Double-dialled longcase clock from Park Green Mill. Y1971.28: https://collection.sciencemuseumgroup.org.uk/objects/co8404934/double-dialled-longcase-clock-from-park-green-mill-longcase-clock

8 For more on the development of UTC see ***The origins of the Coordinated Universal Time (UTC) calendar*** (page 11): https://mosaicprojects.com.au/PDF_Papers/P185-The_origin_of_calendars.pdf

9 For more on ***The Origins of Modern Project Management*** see: https://mosaicprojects.com.au/PDF_Papers/P050_Origins_of_Modern_Management.pdf

To calculate latitude, you need to know the difference in time between noon at the baseline meridian of your charts and local noon. Measuring the maximum azimuth is straightforward, but determining the time difference accurately needs an accurate clock, keeping time as at the meridian.

The concepts and geometry needed for this calculation have been known since the times of Hipparchus and Ptolemy. On land, with enough time and astronomical tables, the local time could be calculated in relation to a base meridian. But at sea on a moving ship, without an accurate time, the only options were either dead reckoning, or applying very complex calculations based on the angle between the moon and the sun in the sky[10].

In 1761 English carpenter and clockmaker John Harrison produced his fourth chronometer (H4), in the form of a large watch. This chronometer was accurate to 5 seconds on a sailing voyage from England to Jamaica, an error of approximately one nautical mile. Despite this success, due to politics and costs, it took many years, and many lives before marine chronometers became standard navigation aids in the early 19th century[11].

Atomic clocks

In terms of accuracy, pendulum clocks were superseded in 1927 when Canadian engineer and inventor Warren Marrison, working for Bell Laboratories in the United States discovered a small pulse of electricity passed through quartz delivers very accurate measure of time. This discovery led to the development of timepieces that use an electronic oscillator regulated by a quartz crystal to keep time.

This crystal oscillator creates a signal with very precise frequency, so that quartz clocks and watches are at least an order of magnitude more accurate than mechanical clocks. While initially very expensive, the development of solid-state digital electronics in the 1980s allowed quartz watches and clocks to be made compact and inexpensive, leading to 'quartz' becoming the world's most widely used timekeeping technology, it is still used in most clocks and watches as well as computers and other appliances that keep time.

Then in 1955 the caesium atomic clock was invented. The first caesium clock was built by Louis Essen in at the National Physical Laboratory in the UK substantially more accurate than a quartz clock, by definition, radiation produced by the transition between the two hyperfine ground states of caesium (in the absence of external influences such as the Earth's magnetic field) has a frequency of exactly 9192631770 Hz. That value was chosen so that the caesium second equalled, to the limit of human measuring ability in 1960, the existing standard ephemeris second which was based on the Earth's orbit around the Sun. This measurement is so precise, scientists are now considering the problems of keeping atomic time and astronomic time aligned[12].

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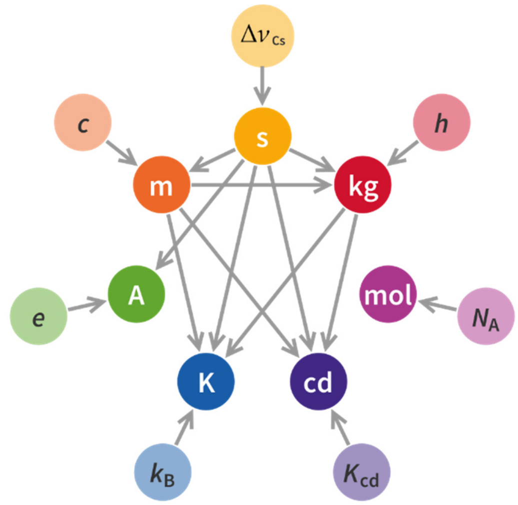
10 Tables to facilitate the calculation of longitude using the moon were compiled at the Royal Observatory in Greenwich from 1766 and published annually as part of the Nautical Almanac. The widespread use of *The Nautical Almanac* by mariners the world over was one of the principal reason Greenwich was selected as the base meridian for the introduction of UTC in 1884. *The Nautical Almanac* is still published annually as a joint venture by the USA and UK governments.

11 The story of Harrison's work and the politics surrounding the development of accurate maritime chronometers is fascinating: https://en.wikipedia.org/wiki/John_Harrison

12 For more on the issue of 'leap seconds' see ***The origins of the Coordinated Universal Time (UTC) calendar*** (page 12): https://mosaicprojects.com.au/PDF_Papers/P185-The_origin_of_calendars.pdf

SI Units of Measure

The International System of Units (SI) is the modern system of measurement. It is a coherent system of units of measurement starting with seven base units, which are the second (symbol s, the unit of time), metre (m, length), kilogram (kg, mass), ampere (A, electric current), kelvin (K, thermodynamic temperature), mole (mol, amount of substance), and candela (cd, luminous intensity). These are now defined in terms of fundamental constants that describe the natural world particularly the second.



The second (symbol: s) is the unit of time was historically defined as 1⁄86400 of a day – this factor derived from the division of the day first into 24 hours, then to 60 minutes and finally to 60 seconds each (24 × 60 × 60 = 86400). The current and formal definition in the International System of Units (SI) is more precise:

> *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.*

Based on this the other units of measure use the second in their definition[13]:

- The metre (or *meter* in North American spelling; symbol: m) is defined as the length of the path travelled by light in vacuum during a time interval of 1/299792458 of a second.
- The kilogram (symbol kg) is defined based on three fundamental constants: the speed of light; the cesium atom's natural microwave radiation; and the Planck constant, which describes the size of the packets of energy that atoms and other particles use to absorb and emit energy.
- The candela (symbol: cd) is the unit of luminous intensity it is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×1012 Hz, Kcd, to be 683.
- The ampere is defined by fixing the elementary charge e to be exactly 1.602176634×10−19 C, which means an ampere is an electric current equivalent to 1019 elementary charges moving every 1.602176634 seconds or 6.241509074×1018 elementary charges moving in a second.

Conclusions

Measuring time is one thing, how people perceive and use time is altogether different. The importance attached to being 'on-time' varies between cultures[14], and simply because we can accurately measure time to the second with our smart phone or watch does not necessarily mean this level of detail is useful[15].

13 For more details see ***2019 redefinition of the SI base units***: https://en.wikipedia.org/wiki/2019_redefinition_of_the_SI_base_units

14 For more on the cultural appreciation of time see ***Perspectives on time!***: https://mosaicprojects.com.au/Mag_Articles/SA1021_Perspectives_on_time.pdf

15 For more on the need for appropriate detail see:
- ***Estimating Fallacies – excessive detail does not help***: https://mosaicprojects.com.au/PDF_Papers/P145_Estimating_Fallacies.pdf

The continuing improvement in the accuracy of time measurements and calendars outlined in this article is likely to continue into the future, but for managers and project controls, we probably only need the level of accuracy developed in the 17th century +/- 10 seconds a day is close enough!

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First Published 7th March 2023 – Augmented and Updated

- ***The Planning Paradox, How much detail is too much?***: https://mosaicprojects.com.au/Mag_Articles/AA022_The_Planning_Paradox.pdf