Origin of the world’s standard gauge of railway is in the interval of wheel ruts of ancient carriages

Masanori OGATA, Kansai University, Suita, Osaka, Japan, ogata@ipcku.kansai-u.ac.jp
Ichiro TSUTSUMI, Polytechnic University, Sagamihara, Kanagawa, Japan
Yoriyazu SHIMOTSUMA, Emeritus Professor of Kansai University, Osaka, Japan
Nobuko SHIOTSU, Research Association of Cultural History, Kobe, Japan

Key words: history of technology, standard gauge of railway, wheel rut, cart and wagon, Tut-Ankh-Amen, the Roman Empire

Abstract: When British engineer George Stephenson laid a railway between Stockton and Darlington in 1825, he adopted 4 feet and 8.5 inches (1,435mm) as the inner distance between the two rails of the track. It is clear that the value became a world’s standard gauge of a railway afterwards. However, few people have interests of its origin. Authors thought that the origin of the standard gauge of the railway might result from an interval of wheel ruts of prehistoric ancient carriages. The authors did fieldwork for a long time to prove this supposition at the ruin of Eurasia, Mediterranean zone and African Continent, also in some museums. In those areas, intervals between wheel ruts which were carved on a street of ancient city were measured, and tread of carriages of traditionally practical use were measured. Moreover, authors investigated some literatures on chariots or wagons excavated from tumulus. As a result, it was proved that a hypothesis of authors’ was approximately right.

1. Introduction
When we walk around ruins of each country of the Eurasia and the African Continent and its outskirts, we can find the wheel track that is considered the traces of ancient carriages. Because the trace of a wheel track was made from a beginning with a purpose, there is a thing left very distinctly [1] as shown in Figure 1. On the other hand, as for many wheel tracks were generated naturally. In this case [2], it is hard to find out because ruins were destroyed more than a thousand years as shown in Figure 2.

Fig.1 Wheel ruts in Ju Yong Guan, near Beijing, China [1]

Production technology of a wheel and the chassis of oxcart and wagon and chariot (two-wheeled ancient tanks pulled by plural horses) which were ancient carriages was handed down to next generation. And it developed to today’s car technology. In other words it may be said that prototype of a automobile is a golden chariot of pharaoh “Tut-Ankh-Amen”of ancient Egyptian civilization. Otherwise, it may be of a chariot of the Hittite who competed for an Egyptian dynasty and hegemony in Orient. Even if it is said that the technology of ancient chariot is

Fig.2 Wheel ruts in Sabratha, Tripolitania, Libya [2]

Fig.3 Comparison of Cambodian oxcart in 10th century with modern automobile in 20th century [3]
common to today’s Formula-I racing cars, it is not exaggeration. One of remarkable examples is shown in Figure 3. We can not find out difference in specifications between oxcart which was appeared in the Middle Ages about thousand years ago and present automobile [3].

2. Fieldwork of wheel track

While investigating distance of a wheel track of the various places in each country on-site for many years, authors noticed that the measuring value was considerably near to 1,435mm (4 feet and 8.5 inches) of standard gauge of the railway of the present day. Table 1 shows result of author’s fieldwork. The place of ruins from No.1 to No.18 is the coastal districts of the Mediterranean in the Roman Empire era. In these eleven places except seven unpublished places, the mean value of a wheel track becomes 1,436 mm actually. From that fact, the authors are sure that the standard gauge of the railway is originated in the wheel distance of ancient carriages. The overall mean value of the wheel track that was measured is 1,431mm till now. The error to a standard gauge of the railway is slightly 0.3%.

Table 1 Measured value of the interval of wheel rut in Eurasia and Africa by fieldwork

<table>
<thead>
<tr>
<th>Surveyed Place</th>
<th>Country</th>
<th>Gauge [mm]</th>
<th>Surveyed Place</th>
<th>Country</th>
<th>Gauge [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pompei</td>
<td>Italy</td>
<td>1,443</td>
<td>14 Zippoli</td>
<td>Israel</td>
<td>1,400</td>
</tr>
<tr>
<td>2 Ercolano</td>
<td>Italy</td>
<td>1,445</td>
<td>15 Cairo</td>
<td>Egypt</td>
<td>unpublished</td>
</tr>
<tr>
<td>3 Ostia Antica</td>
<td>Italy</td>
<td>1,311</td>
<td>16 Sabratha</td>
<td>Libya</td>
<td>1,480</td>
</tr>
<tr>
<td>4 Athens</td>
<td>Greece</td>
<td>unpublished</td>
<td>17 Leptis Magna</td>
<td>Libya</td>
<td>1,485</td>
</tr>
<tr>
<td>5 Kappadokia</td>
<td>Turkey</td>
<td>unpublished</td>
<td>18 Timgd</td>
<td>Algeria</td>
<td>1,455</td>
</tr>
<tr>
<td>6 Perge</td>
<td>Turkey</td>
<td>1,440</td>
<td>19 Khiva</td>
<td>Uzbekistan</td>
<td>1,450*</td>
</tr>
<tr>
<td>7 Pamukkale</td>
<td>Turkey</td>
<td>1,440</td>
<td>20 Rajgir</td>
<td>India</td>
<td>unidentified</td>
</tr>
<tr>
<td>8 Denizli</td>
<td>Turkey</td>
<td>unpublished</td>
<td>21 Hindustan Plain</td>
<td>India</td>
<td>unpublished</td>
</tr>
<tr>
<td>9 Efes (1)</td>
<td>Turkey</td>
<td>1,440</td>
<td>22 Siem Reap</td>
<td>Cambodia</td>
<td>1,200</td>
</tr>
<tr>
<td>10 Efes (2)</td>
<td>Turkey</td>
<td>unpublished</td>
<td>23 Ju Yong Guan</td>
<td>P.R.China</td>
<td>1,145</td>
</tr>
<tr>
<td>11 Edremit</td>
<td>Turkey</td>
<td>unpublished</td>
<td>24 Yun Nan</td>
<td>P.R.China</td>
<td>1,436*</td>
</tr>
<tr>
<td>12 Erzurum</td>
<td>Turkey</td>
<td>unpublished</td>
<td>25 Zi Bo</td>
<td>P.R.China</td>
<td>1,800</td>
</tr>
<tr>
<td>13 Ephesus</td>
<td>Turkey</td>
<td>1,440</td>
<td>26 Amabe</td>
<td>Japan</td>
<td>1,500</td>
</tr>
</tbody>
</table>

Overall average is 1,431 mm. Average from No.1 to No.18 except unpublished is 1,436 mm
* inner distance between wheels. (same as railway gauge)

3. Wheel interval indicated from literature

Together with the field survey, authors examined the excavation report [4,5,6] and the literature [7,8] concerning ancient technology that had been reported in the past. In there, wheel rut, scaled sketch of the wagon and the cart, and the measurement records of them had been reported.

3.1 Road

The oldest road in the world exists in Knossos of Crete of Aegean Sea and is called “The King’s Road”. The road was constructed in the 3rd millennium BC. This road exceeded the Juktas Mountain, passed Gortyn of the southern part of island, and led to Como of the trade port. It was said that the road equipped with groove was constructed at a pass of the Juktas mountain. However, it is unconfirmed in authors’ field investigation.

Moreover, there was processional roads in capital Hattušaş (present Boğazköy) of Hittite Empire that rose in the Anatolia high plateau in Asia Minor from the 2nd millennium BC to the 13th century BC.

In Orient, road “tallakti” for the processation was laid from the 15th century BC to the 7th century BC in Assur and Babylon of Assyria. That road was constructed in Urk of the Achaemenes dynasty of Persian Empire in 4th century BC. In these roads, there were ruts for carriage that were artificially carved. The rut interval almost corresponds to the value of Malta and Crete of
prehistory [7], and the values existed in from 1,380 to 1,440 mm. According to Forbs [7], he guessed the interval of wheel rut was decided by the width of two oxen that pulled carts.

Tyrian Periander of Korinthos in ancient Greece began digging the canal at the Korinthos isthmus of Peloponnesos peninsula in 602 BC. Afterwards, Julius Caeser tried digging in 44 BC and Emperor Nero of Roman Empire also dug in AD 66. At last, the canal was fully opened by Ferdinand de Lesseps (1805-1894) et al. in 1893. The size of the canal is 6343 m in the total length and 23 m in maximum breadth, and height from the sea level is 80 m.

In Greece and Roman era, people put the ship on the carriage and traversed the Korinthos isthmus. The rut "Diolkos" was dug up for the mountain path at that time so that the carriages might prevent escape from the road. About the shape of the wheel track, it was reported that one groove has the width of 200 to 300 mm and the depth of 70 to 200 mm. As for the gauge of wheel track, it is assumed to be 1,380 to 1,440 mm as same as Malta and Gozo Island [7]. Because a railway was laid on just this road afterwards, these details are still unclear of authors' investigation that had been performed in 2005.

Furthermore, authors investigated the road to Acropolis from an ancient Agora, a ruin of Greece and Roman Empire of Athens, Greece. Plural traces of wheel track of carriages that had been used at transportation of marble for construction of the Parthenon were confirmed by authors recently.

3.2 Carriages of prehistory

A real carriage of the oldest is not found out yet until today excepting "Tut-Ankh-Amen's chariots". However, we can see an expression of the oldest carriages by "the Standard of Ur" of Sumer, ancient Mesopotamia of 2600 BC. A carriage has four wheels. A wheel is assembled by two pieces of solid plate made of wood. Carriages are like tanks pulled by four "onagers", a kind of ass.

Complete sketch of carts and wagons of 2nd millennium BC that was excavated in Lchashen of a Sevan lakeside of Armenia has been reported [4]. As shown in figure 5(A), the cart has two wheels which were assembled at five pieces of wooden solid discs jointed. Approximate center gauge of a wheel estimated by authors is a minimum of 1,442 mm and maximum of 1,770 mm, average was 1,606 mm. Another one is shown in figure 5(B). The wagon has four wheels which were assembled at three pieces of wooden solid discs jointed. In this wagon, approximate center gauge of a wheel estimated by authors is a minimum of 1,310 mm and a
maximum of 1,606 mm, average was 1,458 mm. As the interested thing, the great scholar Stuart Piggot, who is an expert about an ancient transportation vehicle, has mentioned in his literature that “In the prehistory, it is thought that there was already a standard about a gauge of a carriage” [4] as shown in Table 2.

Table 2 Specifications of Wagon in the Bronze Age *

<table>
<thead>
<tr>
<th>Excavated from Trialeti, Gruzia Radiocarbon date 1420±60 BC</th>
<th>Wagon A from Barrow XXIX by Piggot, 1966</th>
<th>Wagon B from Barrow 5 by Juparidze, 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole picture</td>
<td>Measured in Tbilisi, Gruzia after excavation</td>
<td>Scale drawings</td>
</tr>
<tr>
<td>Wheel number</td>
<td>4 (3 parts, solid disc)</td>
<td>4 (3 parts, solid disc)</td>
</tr>
<tr>
<td>Wheel diameter</td>
<td>1,150</td>
<td>1,150</td>
</tr>
<tr>
<td>Nave length</td>
<td>350</td>
<td>400</td>
</tr>
<tr>
<td>Gauge or wheel-track</td>
<td>1,400</td>
<td>1,450</td>
</tr>
<tr>
<td>Axle to axle length</td>
<td>1,500</td>
<td>1,200</td>
</tr>
<tr>
<td>Overall length over two wheels</td>
<td>2,650</td>
<td>2,350</td>
</tr>
<tr>
<td>Flooring of body</td>
<td>decayed</td>
<td>1,700×1,000</td>
</tr>
</tbody>
</table>

*) The table was created by authors after excerpted from ref. [4]. Unit [mm]

Chariot that had been made at 2nd century BC to 1st century AD was excavated from Celtic ruins of Wales, UK. The restoration drawing was reported [5, 6]. It is a two-wheeled cart as shown in Figure 6, and the wheel is not a solid disc any longer. A wheel has 12 spokes. The center gauge of the wheel is about 1,422 mm (4 feet and 8 inches). The value is miraculously corresponding to the railway gauge that George Stephenson applied first. This is mentioned later in chapter 5.

4. Assumption of standard in wheel track

Authors pay attention to “military specifications” that is thought one of the origin of wheel tracks. A marching standard of the armed forces in ancient Greece and Rome was one double step. One double step of the present day’s standard is 1,524 mm (just 5 feet).

The common scale in measuring length of both eras was 296.7 mm. 1 noig in Greece is equal to 1 pes in Rome, this is equal to 296.7 mm. One double step, one passus in Roman Empire is equal to 5 pes, so the figure becomes 1,483.5 in millimeters. Authors regard this figure of 1,483.5 mm as a distance between the wheel center shown in figure 7. Suppose that one offset per one wheel from the center of a rail is 1 Roman inch (24.7 mm). Consequently the rail gauge becomes 1,434.1 mm. This value corresponds almost to the standard gauge of a railway of 1,435 mm. This assumption is not thought to be much irrational.
5. Railway gauge and wheel track of Roman roads in Britain

Prosperity of railwa7 was affected considerably by the invention of high performance boiler and development of steam locomotive. In the former age, the horse tramway was used for the land transportation of the person and goods. The cart and the wagon utilizing Roman roads were used for transport in an older age.

The railway birthplace “Britain”, it started from Julius Caesar’s expedition in 55 BC and 54 BC, were ruled by the Roman Empire, and the sovereignty continues till the invasion of Saxons of AD 449. The maintained road was not in Britain in those days. The Roman roads for the supplies transportation to the forts and the colonies were constructed by the Roman engineers everywhere in Britain. “- chester” and “- cester” show the places of Roman colonization.

Authors guess that they laid the rail of the horse tramway on the Roman roads, and used it for the transportation route until the steam locomotives are invented. The sleeper (wooden board) or the stone plate was put in parallel with the groove to close the ruts that had been carved for the stone pavement and the rail was laid on that. Inevitably, the gauge of the rail is thought to become equivalent to the wheel intervals of the carriages of the Roman Empire age. The reason why the sleeper was put on parallel to the grooves is that there is an obstacle if the horse runs when the sleeper was squarely laid to the rail. So that there is the width of paper, authors recommend the reader to refer the literatures of the trolley of the colliery [9], the rail in the railway, and the development of the wheel [10-13].

British engineer Richard Trevithick (1771-1833) succeeded in the trial run of a practical steam locomotive on February 21, 1804. The route of the horse tramway between Merthyr Tydvil and Abercynon was used. Therefore, the wheel has no flange but the rail was flange type of L shape. The rail was called “plate rail”, or “the Butterley Rail” taken from the name of factory.

On the other hand, George Stephenson (1781-1848) has succeeded in the test drive of the steam locomotive “Blucher” of the first-ever flanged wheel on July 25, 1814. Steam locomotive was manufactured by the “Wagon Shop”. There is the Killingworth colliery nearby. Trolleys and horse tramway were used to transport coals in those days. The colliery is in the north of Newcastle, northeastern part of present England. Stephenson was working as an engineer in the colliery. In those days, the gauge of the horse tramway had not been standardized, so some gauges were being used. It is said that he decided 4 feet and 8.5 inches (1,435 mm) the gauge of steam locomotive in consideration of the divergence of the rail and the turn of a locomotive. It seems to result from 4 feet and 8 inches of the gauge of the horse tramway that had been used in Killingworth colliery. There are some anecdotes [11, 12, 13] for the decision of the railway gauge. However, it is not certain which is true. Afterwards, Stephenson worked on the improvement of the steam engine. The first commercial railway in the world was opened by “Stephenson Gauge” (present standard 4 feet and 8.5 inches) between Stockton and Darlington in steam locomotive “Locomotion” on September 27, 1825. Robert (1803-1859) the son of George Stephenson manufactured a steam locomotive “Rocket”, and they won the laurels of “Rainhill Trials” on October 8, 1829. In the next year, they succeeded in the opening of the interurban railway between Liverpool and Manchester on September 15, 1830. “The Age of the Railway” began brilliantly from here.
There was a rival of the railway at the same era. His name is Isambard Kingdom Brunel (1806-1859). He adopted 7 feet and 0.25 inches (2,140mm) for the gauge of the Great Western Railway. It was called the broad gauge. His father's Sir Mark Isambard Brunel (1769-1849) was a great engineer as well as the Stephenson family. They also appear in "The Battle of the Gauge". It was decided that the gauge of Stephenson's 4 feet and 8.5 inches (1,435 mm) was finally a standardized gauge of the British railway by "Railway Regulation Gauge Act" in 1846. It became a railway standard in the world in less than no time.

6. Conclusion

Authors have surveyed ruins of Eurasia and African continent for long years. In the ruins, we had found the wheel tracks and had measured rut interval (tread of a modern automobile) of ancient carriages. From the results of wheel intervals by those measurement values and of the literature investigations concerning the carriages, the origin of the international standard gauge of present railway was able to clarify. It can be said that the origin exists in the wheel intervals of ancient carriages.

Technology developed rapidly in the Industrial Revolution age of Britain. At that time, the parent and child of Stephenson and of Brunel had a hard time in the gauge decision of the railway without thinking about ancient technology at all.

Consequently, the standard gauge of the railway was surprisingly corresponding to the value that the ancient engineers of 3000 or more years ago had applied to the carriage production technology. We can clearly feel in the age the influence that human being's sense exerts on the engineering and technology.

References