The Harnessing of Power

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How 19th Century Transport Innovators Transformed the Way the World Operates

By

Maxwell Gordon Lay

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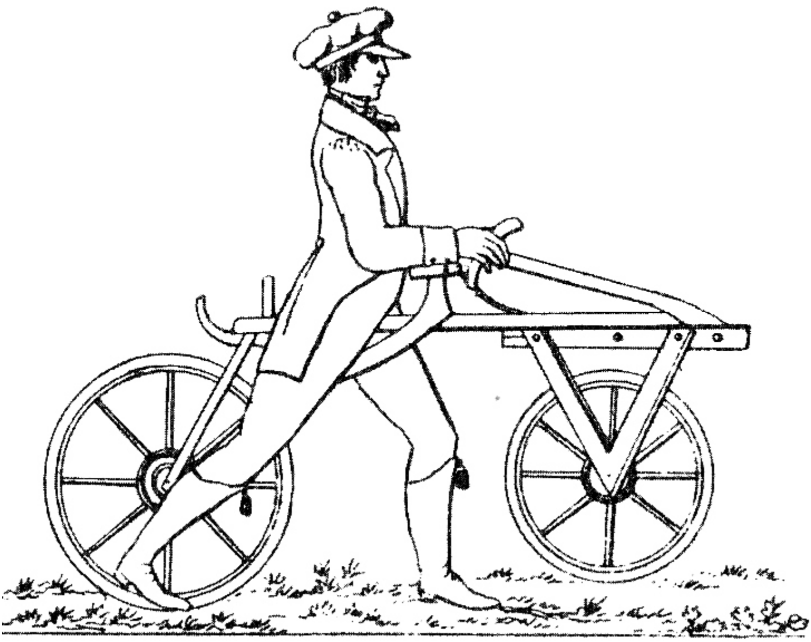
This book is dedicated to my dear wife Margaret who has supported me throughout its creation and production, to Robbie and Jasmine who provided constant reality checks, to all the librarians who have aided me at all times and to the wonderful access facilities provided to all modern authors by the services of Google, Wikipedia and Amazon.

A chariot can be made that moves with incredible speed without horses.
Roger Bacon, c1270



CONTENTS

Part 8: Steam: A New Source of Useful Power

Part 9: The Transport Revolution is Underway

Part 10: The First Commercial Railway

Part 11: The Consequences of the New Railways

Part 19: The Context of Change

PREFACE AND INTRODUCTION

I was led to write this book as I prepared and presented an international review paper on the factors that had influenced road development in the 20^{th} century.[1] I drew somewhat glibly on the 19^{th} century legacy that provided the basis for most of those 20^{th} century events. The question that increasingly came to my mind was how that creative 19^{th} century legacy had arisen? How did transport reach the transformative stage that it did at the end of the 19^{th} century – so many changes, so many new technologies, so many new markets?

As I thought more about these matters I came to realise the astonishing extent of the transport changes that had occurred in the 19^{th} century. Nothing like it had ever occurred before, and the 20th century was mere incrementalism compared with the quantum changes of the 19^{th} century. What a story there might be to uncover and to use to shed more light on our transport inheritance – where did all the 19^{th} century's key transport features come from and why are there so many inventions, innovations, inconsistencies and illogicalities in the story?

Hence this book, which is my attempt to understand the origins of much of our current transport world. I write it as an engineer specialising in transport and certainly not as an historian additionally steeped in matters of economics, or politics or social structures. There were many great and fundamental changes occurring during the 19^{th} century and my transport specialisation was just one sub-set of those changes. It is appropriate therefore for me to use the words of a leading English historian – Kitson Clark – to provide a broader context for my story. He described events of the 19^{th} century as:[2]

> *"a larger movement in history ... which went on throughout the 19^{th} century ... and which swept through human affairs and carried away the ancient régime with its aristocracies, its hereditary monarchies, its prescriptive rights and left in its stead a world whose values, on the whole, we still accept."*

I have written this book in my home town of Melbourne, Australia. Melbourne was not founded until the mid-1830s so I can view the 19^{th} century without a strong parochial view. Indeed, my self-assigned task was to take world view of 19^{th} century transport changes. Nevertheless, much of the book has a strong British orientation as without question the Industrial Revolution was a period and a process predominantly initiated and implemented in Britain. However, when the Revolution lost momentum in mid-century – or entered its second stage in the view of some commentators – Britain steadily began to lose its leadership role. By the end of the century France and south-western Germany were dominant change-makers and the USA was appearing on the horizon. How Britain lost, or even threw away its leadership, is a story that I explore within the wider thrust of this book.

Finally, I have tried wherever possible to highlight and pay homage to the many individual inventors and innovators and entrepreneurs who caused the dramatic transport changes that occurred during the 19th century. It will become apparent that they did this through individual initiatives to satisfy personal rather than corporate or national goals. And they were often hindered rather than aided by the various arms of officialdom.

I should note that after I began writing this book I came across a remarkable book published in 2005 by Smil covering a similar topic but with different emphases for the period from 1870 to 1914. I see this work as complementary rather than contradictory.

Note on units used. The text employs the ISO SI (Systéme International) metric units used in most countries but not, unfortunately in Britain and the USA. The main different unit is the kilometre, so to obtain miles or miles per hour, multiply the number by 0.6. For mass, I have assumed that British ton and the SI tonne are identical, whereas there is actually a 10% difference. For engines I use the SI Hertz which is a cycle per second and therefore equivalent to 60 RPM as RPM uses minutes rather than seconds. For power, the SI unit is the Watt and to convert kW to horsepower, multiply by 1.3.

Endnotes

[1] Lay 2007
[2] Kitson Clark 1962:33

PART 1

THE 19TH CENTURY'S TRANSPORT INHERITANCE

CHAPTER 1A

A LOW SPEED WORLD

The word *transport* embraces the processes that occur when people and objects move from place to place in a purposeful way. Even the earliest human communities required transport to collect and distribute food and water. However, transport is rarely a simple task and mankind has frequently sought ways to modify and improve it.

One noticeable early transport change occurred when our ancestors began to travel across the ground by walking on two legs. Once this major change had occurred, transport then changed at a minimal rate over the millions of years between that event and the beginning of the nineteenth century. This book explores the minimal changes that did occur and then focusses on the causes and consequences of the dramatic transport-related changes that arose during the 19th century. The focus on transport will not produce an introverted world view for it has been well said that "*the vital significance of improved transport to economic development is one of the few general truths which it is possible to derive from economic history*."[1]

Whilst two-legged walking and running delivered many benefits, they had obvious transport short-comings. If we compare our unaided human transport performance when travelling on land with our equivalent performance when riding a simple bicycle (Chapter 2) or a skate-board, it is clear that as transport devices humans soon reached an evolutionary dead-end. The mechanical process involved in two-legged walking and running are inherently inefficient as, at each step, the human body mass is moved with much wasted effort in directions other than the travel direction.[2] Further, compared with the simplest hinge, the joints in our human limbs are poor pieces of mechanical engineering. Even if such inefficiencies were removed, there would still be no prospect of humans matching the minimal energy needs of a rolling wheel or of a sliding sled.

Humans walk and run at about the same speed as many other land-based animals. In terms of energy consumption, the optimum travel speed for a human is about 6 km/h, which most people would consider to be a fast walk.[3] Adults change from a walking to a running gait at around 9 km/h.[4] Trained runners can initially move at about 40 km/h but after 300 m most runners drop to an aerobic balance speed closer to 25 km/h.[5] The current world record for a marathon implies an average speed of about 20 km/h over two hours. Smil[6] gives a comprehensive review of human speed, energy and power capabilities.

A few animals can travel over land faster than humans for short periods but, as travel times lengthen, the number of animals that can out-distance the human quickly diminishes. Indeed, over many days the human can out-distance all other land-based animals. A common rule of thumb was that a *footman* could run down a horse in several days and the best horse in about six days.[7] In the 18th century a single skilled footman could travel about 120 km per day. For example, in the 1780s the Compte de Ségura used a footman to exchange a treaty between Russia and France. The courier covered the 1080 km from St Petersburg to Paris in 18 days, or 120 km per day.[8] This averaged at walking speed over the entire 24 hour day. Indeed, in most pre-19th century cases personal travel occurred at walking pace.

In pre-19th century Europe most journeys from town to town for most people would take at least a day. The major exception was in the large migratory movements that occurred with seasonal variations in climate. Whilst these could involve large distances, they nevertheless still occurred at walking speed.

The ability to routinely travel long distances quickly was not an important human need and thus received little evolutionary priority as we evolved in what we would now consider to be a low-speed world. One associated consequence is that we have a poor visual ability to determine the speed of an oncoming object and we then take many seconds to react to our observation. Instead, we have evolved the ability to detect and identify another creature a kilometre away, giving us minutes to decide what to do before an encounter might occur. Likewise, we have not needed to evolve any significant resistance to impact by large moving objects. In our low-speed world the threats and opportunities have been relatively local and so we react quickly to nearby unexpected events and have a remarkable ability – called *peripheral vision* – to detect moving objects at right angles to the direction in which we are looking. The various other human factors that affect

In the low-speed world it was widely believed that ill would befall any humans who travelled at higher speeds. For instance, it was commonly believed that air breathed in when travelling at speed would crush the lungs and the brain would be forced into permanent hallucinations. People who fell off cliffs would never experience any pain on final impact as they would already be dead as the speed of the fall would have made it impossible for them to breath. The view that rapid motion could cause apoplexy was behind an 1837 Whitehall instruction to a judge travelling by horse-drawn coach from London to Edinburgh that he should at least stop for the night at York for "*if you go all the way by that coach it will force the blood into your head and you will die*".[9] In 1840 a then well-known British writer on science and technology, Dionysius Lardner, claimed that people travelling at speed of 190 km/h (in an out-of-control steam locomotive) would be unable to breathe and would therefore die from suffocation.[10]

A lack of speed perception did cause many fatalities and serious injuries at the beginning of the steam train era (Chapter 12). For example, the case of a major British politician being very publicly run-over and killed when he misjudged the speed of an oncoming train is discussed in Chapter 10b. Similar problems arose when people leaned out of a moving train and were struck by a trackside object or when they stepped from a train before it had completely stopped. Dionysius Lardner had properly advised early train travellers "*Never attempt to get into or out of a railway carriage when it is moving, no matter how slowly, for it is a peculiarity of railway locomotion, that the speed, when not very rapid, always appears to the unpractised passenger to be much less than it actually is*."[11] The advice remains valid today and, as can be seen with young children, judging speed remains a learnt rather than an inherited evolutionary ability.

Transport often involves moving objects. Humans struggle to carry loads which are only a fraction of their body weight. Other "stronger" creatures that can carry loads without external help can rarely move more than half their body weight.[12] By comparison, the load capacity of a wheeled platform can be many, many times greater than the weight of the platform. The next Chapter will describe how, as agriculture developed, this human inadequacy led to the first transport invention and the need for humans to carry heavy weights continued to receive little evolutionary priority.

Clearly, improvements in transport, specifically in travel speed, in load-carrying capability, and as a tool for war and conquest, required invention rather than evolution. Thus transport invention was driven largely by the needs of increasingly organised communities to move freight for food and trade, to meet the demands of warfare and to efficiently administer large territories. It is appropriate to now briefly describe that process as it continued over the millennia, before peaking in the 19th century – a period which will be described in much more detail in later Chapters.

CHAPTER 1B

THE FIRST TRANSPORT INVENTIONS

Our evolved personal transport capabilities were unable to meet the needs of developing communities. Consequently, transport improvements started to occur through invention rather than evolution. The first major improvement followed from the discovery in about 5000 BC that some breeds of cattle could be domesticated and that castration made it possible to train them to do useful tasks. This particularly applied to oxen which had prominent shoulders which made it relatively simple to develop harnesses that enabled the animals to pull the primitive ploughs needed to extend agriculture beyond a subsistence level. It was then a small step to move from pulling a plough through soil to dragging a sled able to transport useful loads over smooth ground.

Oxen were strong and able to operate on poor ground, however they moved very slowly at less than human walking speed. Another six millennia were to pass before horses could be used for haulage as a horse does not have prominent shoulders and its harness must be carefully designed, constructed and operated to avoid pressing on its windpipe. Many societies were unable to do this, and effective horse harnesses for freight applications were not widespread until about 750 AD.[13] Horses were also extensively used to carry freight on their backs and could manage loads of about a third of their body weight.

Moving an object requires overcoming *forces* due to friction and gravitation. Technically, the *energy* needed is the product of these forces and the travel distance. The effort needed to haul an object is indicated by the time rate at which the haulage task consumes this energy and is called motive *power* and is fundamental to the story in this book. Indeed, it has been argued that power as we know it is the great discovery of the 19th century.[14] It is measured in Watts (or Joule/second) and has the symbol W. Humans can produce about 50 W whereas oxen and horses provide about 500 W. This order of magnitude improvement highlights the importance of learning how to harness animals and utilise their power. Indeed, the first practical internal-combustion engines still only provided about 500 W (Chapter 14). Although an ox could, typically, haul a larger load and thus technically do more work than a horse, the greater speed of the horse meant that it usually provided more power than the ox.[15]

A sled dragged slowly across ice is a situation requiring minimal motive power. There are obvious limits to the usefulness of this application and the frictional forces produced when dragging a sled across land can be very high. The alternative is the wheel which avoids the large friction forces by ensuring that most relative movement occurs in the controlled environment between the wheel hub and the fixed axle. By 3000 BC a number of wheeled devices had been invented and operated.

A few definitions to be used in this book should be introduced here. A cart is a two-wheeled and a wagon is a four-wheeled load-carrying vehicle. A dray is a cart without sides. In the 19th century the more common spelling was "*waggon*". A carriage is a vehicle for conveying people and was called a coach if the passenger space was enclosed. These three vehicle types do not have their own power source. A car is a self-powered carriage. A truck is a self-powered wagon. In Britain, the word "*lorry*" is sometimes used instead of "*truck*". The text uses the British term tyre rather than "*tire*", although "*tire*" was the original 19th century word and has a correct linguistic basis. "*Tyre*" became common in Britain in the 1930s.

The wheel was not a simple development and wheeled vehicles never occurred in a number of otherwise advanced communities. Furthermore, the technology for making or the wealth for buying wheels and wagons was not widespread. In 1800 at the start of our revue period, there were still parts of Scotland, Wales and the English west country where wheeled vehicles were unknown.[16]

When the technical challenges were met, the wheeled vehicle brought many advantages and improvements. However, for the five millennia following its first invention, the wheel provided a far from perfect outcome. Wheels were difficult to make, they were often cumbersome, they separated from their axles, and their axle hubs and running surfaces wore very quickly. In the 1790s cast iron (Chapter 5a) was used to provide oil-lubricated joints between the rotating wheels and their fixed axles, thus dramatically reducing a millennia-old operating problem. The method was patented by John Besant in 1795 and was first used on Britain's Royal Mail coaches as will be described in Chapter 1e.

There were two further, related, problems. The stiffness of the wooden or iron running surface of the wheels meant that very high contact pressures occurred between each wheel and any hard and trafficable road surface, causing both to wear rapidly. On the other hand, if the road surface was relatively soft, the wheels would sink into the roadway, greatly increasing the traction forces needed and making the road far less trafficable.

These contact pressure problems could be alleviated by making the wheel running surface wider, but the wheel then became much heavier. Another common solution was to make the wheel radius bigger which increased the effective contact area between the wheel and the road and thus reduced the damaging pressures. However it also raised the body of the vehicle making it difficult to load. It also made it impossible to have a steerable front axle for the wheel could not fit under the vehicle when the steering axle turned about its central vertical axis (Fig. 1).

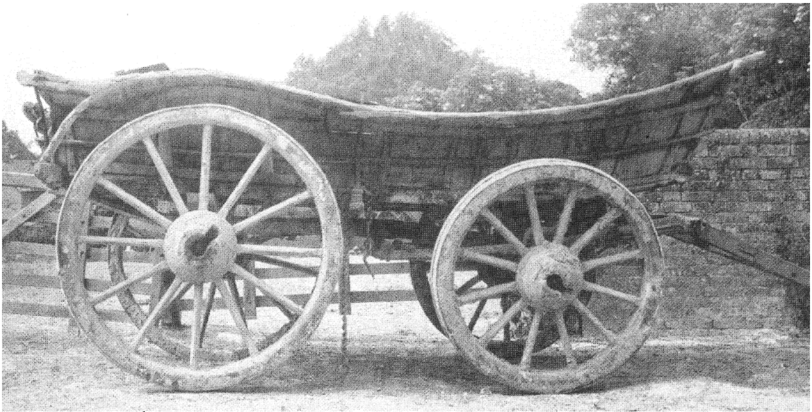


Fig. 1 A 19th century wagon with high wheels, demonstrating their effect on wagon height and steerability. From Lane[17].

The vertical loads produced by the mass of the wagon and its freight bore on the pavements via the wagon wheels and often resulted in significant pavement damage. This led to much argument and a great deal of empirical and fruitless pursuit of dead-end developments, such as the contorted production of dished and conical wheels to carry heavy loads.[18] A variety of wheel shapes had been proposed and used during the 18th century (Fig. 2) and the debate about the appropriate system was still raging at the end of the 19th century. The issue was finally swept away by the wide-spread use of the pneumatic tyre early in the 20th century (Chapter 16a). These tyres automatically ensured that contact pressures did not exceed the inflation pressure of the tyre. Nevertheless, in the 19th century most motor trucks ran on wheels with solid rubber running surfaces, which were only slightly better than iron surfaces.

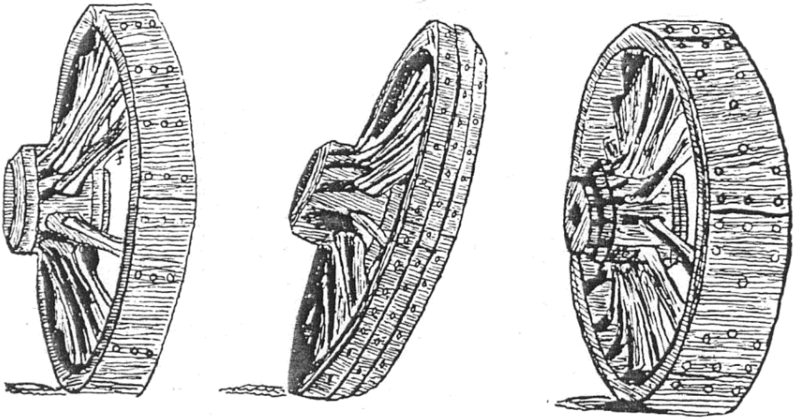


Fig. 2 Wide dished and conical wheels developed prior to the pneumatic tyre in order to minimise contact pressures and to carry heavy loads. See Fig. 4 for a further explanation of the wheel in the centre. From Pyne[19].

A wagon weighed about a ton (about the same as a modern car) and could carry up to 8 ton.[20] A typical loaded wagon would travel at walking speeds or less and its movement was truly "*ponderous*". The great wagon journeys across the USA in the 1840s averaged about 25 km per day or about half walking speed.[21] Whilst ascending even a gentle up-slope was a problem for the heavy vehicles, descending hills was often more of a problem, as the lack of adequate braking meant that vehicles could easily begin rolling out of control towards the hauling beasts or into roadside ditches, with disastrous consequences.

Wheels were not essential for improved personal land transport. By 3000 BC horses had been tamed sufficiently to permit horse riding to occur. This was followed by the use of light two-wheeled chariots. Selective horse breeding was widely practised, and specific lines were bred for a range of purposes.

The use of reins attached to transverse pieces (*bits*) in the horse's mouth greatly increased the control that a rider could exert over a horse. Metal "*bits*" were not invented until about 900 BC. The introduction of foot stirrups in about 200 BC finally made horse riding an easy means of personal transport and greatly improved the weapon-wielding effectiveness of a warrior on horse-back. With good reins and stirrups and a strong horse, a single horse and rider could then manage about 70 km per day. In conjunction with a well-organised stage system using a series of horses, messages and small packages could be carried about 250 km per day, at an average speed of around 10 km/h. This was about twice the speed of a single man on foot, but did require pre-organised stages. Furthermore, stabling was required along the route as at each staging stop the rider’s horse was replaced by a fresh, rested horse.

CHAPTER 1C

ALTERNATIVES TO THE WAGON

As societies moved beyond subsistence levels, the need to move products led to a steady increase in the use of animal-drawn wagons for freight haulage. However, at the best a horse could haul a load of about a ton over short distances or half a ton over long distances. Consequently, freight capacities were extremely small and the pressure for change came more from a need to increase the size of the loads that could be carried than from a need to increase travel speeds.

The movement of freight is of paramount importance to any developing economy. It has been estimated that the haulage task on roads servicing London grew by a factor of over three between 1800 and 1840.[22] Textiles were a major contributor to this increase. It is relevant to underline that this rapid growth was occurring before the railway era began. At the advent of railways in England, there were over 2000 regular wagon services per day.[23] Assuming a modest load of 5 ton (Chapter 1b) suggests that at least 10 000 ton a day was being moved on Britain's pre-railway roads. Whilst much of this growth was due to the new industrial processes, some was also a consequence of the end of the Napoleonic Wars in 1815 and the subsequent refocussing of attention on internal developments.

Significant amounts of freight were also moved by water. There is a long history of using sailing ships and galleys to move freight between Mediterranean ports.[24] In Britain there were regular movements of grain and coal along the east coast. The tonnage capacity of the ships engaged in British coastal shipping increased from 330 thousand ton in 1790, to 830 thousand ton in 1824. This is much faster than the general growth of economic activity during the same period. In 1824, some 5 million ton of coal and half a million ton of grain were moved by British coastal shipping.[25]

Although these very large volumes and tonnages of freight could be moved by sea between suitable ports, the process could also be extremely slow, as the basically square-rigged sailing ships predominantly travelled down-wind and were thus exposed to the vagaries of the weather and as – without adequate time-keeping – navigation was often haphazard and wildly inaccurate.[26] Ships rarely exceeded walking speed and even in the 18th century ships sailing from England to Australia in favourable conditions typically had average speeds of about 10 km/h.

In some inland locations, large quantities of freight could be floated down rivers and since the Middle Ages many European rivers had been modified to make this process more effective. Large communities had developed canal-like systems for water supply and drainage. In order to enhance the economic potential of tracts of countryside, major inland canals capable of carrying horse-drawn barges were built in Britain and continental Europe from the mid-16th century onwards to a usage peak in the 18th century.[27]

Many of the British canals were built by groups of speculators and investors and their main customers were the producers and consumers of coal. For example the Bridgewater Canal (Chapter 10a) had been built in the 1760s by James Brindley to take coal from the Duke of Bridgewater's mines at Worsley to Manchester, some 10 km to the east. It crossed the River Irwell on an aqueduct. Operation of the canal halved the price of coal in Manchester. Within a few years there were major extensions east to Runcorn on the Mersey River estuary and to collieries at Leigh. The horse-drawn canal system that resulted from such investments provided the transport backbone for the initial phases of the Industrial Revolution.

Large-scale canal development also occurred in the USA between the 1812-4 war against Britain and the beginning of the railway era a few decades later. Major works such as the Erie and Pennsylvania canals were built to enable America to peacefully develop its vast lands east of the Appalachians.

Typically, one canal barge carried as much freight as 12 horse-drawn wagons. Haulage capabilities demonstrate the difference between transport modes. At the beginning of the 19th century a well-harnessed horse could pull a load of 1 ton on a good level road for up to 5 km. For longer distances, the capability dropped to about 0.5 t. When iron rails became available (Chapter 9c), the smoother surface meant that the same horse could then pull a load of 8 t. Further improvements in haulage capacity occurred with canals and their tow paths, where the flat gradient and low resistance to motion allowed a horse to haul 50 t loads.[28] An important factor with canals is that the resistance to motion depends only on the cross-sectional area of the barge, and so the resistance per ton carried reduces as the load hauled and the barge length increase (Chapter 9f).

In pre-railway England, many of canals were very profitable investments. For example, in 1825 the ten best performers returned an average annual dividend of 28%. A major cargo was coal produced at

England's inland coalfields and needed throughout the country, particularly as the use of coal gas for power generation and lighting became more commonplace (Chapter 15a). Canals also provided passenger services for, although much slower than wagons, they were far more comfortable, and in 1836 the Union Canal was carrying about 600 passengers per day between Edinburgh and Glasgow.[29] Passenger services were also improved with the introduction of long and light shallow draft boats. When hauled by trotting horses these "*swift boats*" could reach speeds of 15 km/h, surfing on their own bow waves.

The above figures neatly illustrate a prime reason for investing in transport facilities, even in the absence of mechanical power. That reason is that maintaining momentum is a relatively undemanding task when the resisting forces of friction and gravity have been minimised by appropriate transport infrastructure.

CHAPTER 1D

PERSONAL TRAVEL

For most people, walking was the only available means of travelling within towns and between towns. It was still a very common means of long-distance travel in the 18th century. For instance in England many soldiers would be encountered being redeployed around the country or travelling to and from training camps and embarkation ports.

A revealing mid-18th century travel example occurred when the famous blind English road-builder, John Metcalf (Chapter 4a), was in London with his local member of Parliament, a Colonel Liddle. Liddle offered Metcalf a ride home to Knaresborough in his carriage, a journey of some 300 km. Metcalf declined and said he preferred to walk home. Blind, on foot, and unfamiliar with route, he completed the journey in 6 days. The Colonel and his carriage took 8 days.[30]

Personal travel by riding on the backs of animals or in animal-drawn vehicles was a matter of perceived convenience and not of time saving. Until the 18th century, there was little difference between vehicular personal travel and freight haulage as both used wagon-style vehicles which travelled at walking speed (Fig. 3). Much of the technology appears to have been of Celtic origin. The Celts began building light and sophisticated wheels in about 700 BC.[31] Key features were spoked wheels with applied wear-resistant running surfaces. Iron was widely used in Celtic vehicles and harnesses. A prime example of an early Celtic vehicle with many advanced features is the Dejbjerg wagon from about 50 BC and found well-preserved in the 1870s in a Danish swamp (Fig. 3a). The reconstructed Roman passenger vehicle in Fig. 3b is quite advanced as it also has strap suspension and a swivelling, steerable front axle.

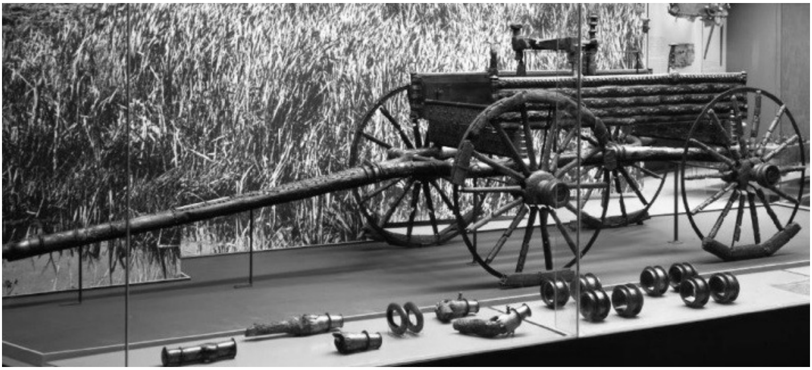


Fig. 3a A reconstructed Celtic vehicle from about 50 BC. It was found in a Danish swamp at Dejbjerg in the 1870s. In the Danish National Museum. Photo, wordpress.com via Wikipedia Commons.

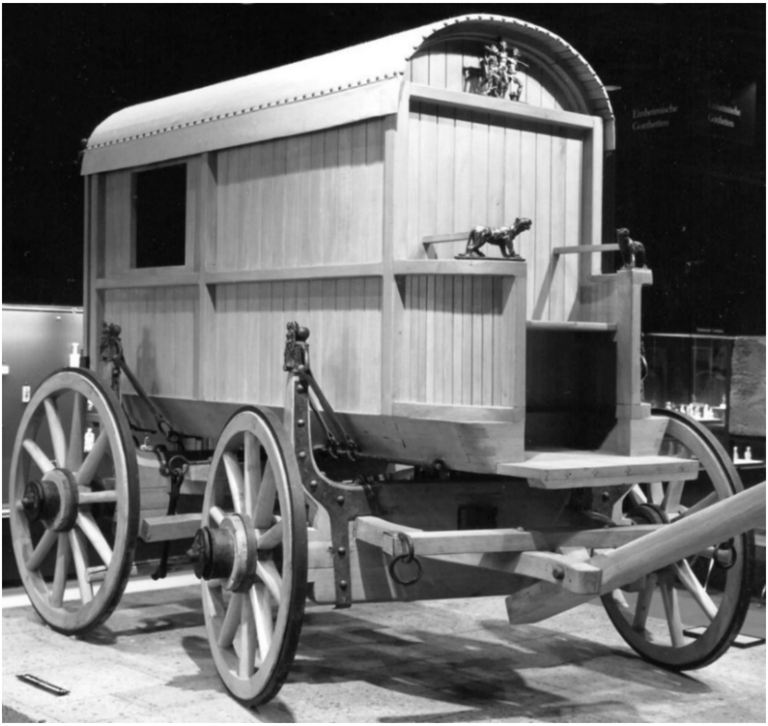


Fig. 3b A reconstructed Roman passenger vehicle in Cologne Museum. Both the front axle and the harnessing shaft pivot around a central vertical pin. Photo with kind permission of the Rheinische Bildarchiv, Cologne.

Wagons for transporting people came into prominence in the 13th century although – as shown in Fig. 3 – many of the innovations were reinventions of much earlier Celtic technology. A key need was to provide passengers with a smooth ride. However, a wagon with four rigidly attached wheels will always provide a rough ride on road surfaces which are not perfectly flat planes. This is because, as a matter of geometry, the rigid wagon can only make contact at three points. The fourth point is poised above the road surface, ready to descend with a rattling bump. The Celts found a way around this problem. They had developed good leather-working skills for harness making, and were able to make leather straps to suspend the vehicle cabin, as can be seen in Fig. 3b. This reduced the previous abruptness of the bumps and the Roman philosopher Seneca said that his carriage travelled so smoothly that he could write whilst on a journey. The term "*suspension*" is still used to describe ride-softening devices in modern vehicles, although they no longer work as suspension devices.[32]

Vehicle technology only slowly improved over the next millennium. The main developments were better harnesses and lighter and stronger wheels. Increases in travel speed above walking began to occur early in the 17th century, mainly as a consequence of greater demands by the wealthy for personal travel and, at the supply end, to a wider use of iron in vehicle construction. This use of iron introduces a main thesis of this book (Chapter 6).

Iron had many useful transport applications. However, iron making was still a craft rather than a manufacturing process, so its spreading use in vehicles indicated strong market demands. As discussed in Chapter 1b, the use of iron for bits and stirrups greatly enhanced the usefulness of horse riding. For vehicles, iron rivets simplified the attachment of the hauling part of the harness to the vehicle being hauled. Iron studs and plates were used to prevent the rapid wear of wooden rims and iron pins were used to retain the wheel on the axle. The wearing surface between the wheel and the axle was a major operating problem. The bearing surfaces themselves were heavily lubricated with animal fats and occasionally employed some cylindrical metal pieces although these were more likely to have been the softer bronze, rather than iron.

Iron coil springs were invented in England in 1625 and were soon used to support coach bodies at each of their four corners. A major advance demonstrating the increasing availability of useful pieces of iron occurred in the 1660s in Prussian Berlin where Philip di Chiesa, a person of Italian extraction born near Avignon, greatly improved the rideability of coaches by hanging the leather suspension straps from cantilevers made of flat iron bars (Fig. 4).[33] Such leaf springs are still used in many current vehicles. Di Chiesa's vehicles were called *Berliners*. They were relatively large with an enclosed passenger area. The leather straps were subsequently replaced by iron links.

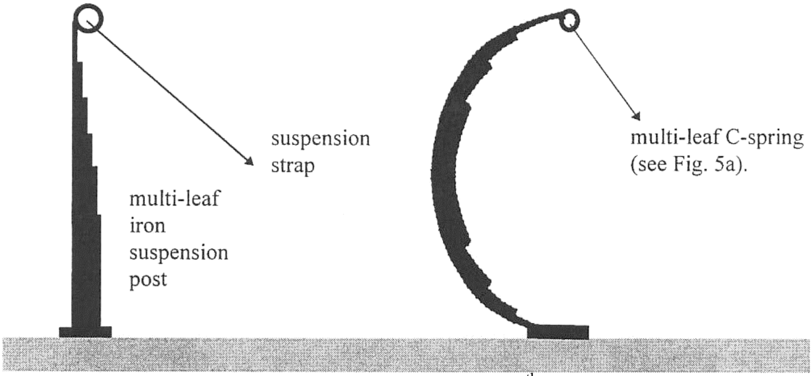


Fig. 4 Iron leaf spring suspensions from the late 17th century. Depending on its shape, the C spring might also be called a circular or an elliptical spring.

Germany was then the centre of quality coach-building. Increased competition from the German *Berliners* led to further developments in Britain, including the work of the multi-talented Robert Hooke and his definition and scientific measurement of the elasticity of iron in the 1670s.[34] Elliptical leaf springs (Fig. 4) were developed by Obadiah Elliot[35] in London in 1804 and Chapter 1f describes how they produced a quantum jump in coach performance. Elliot was a well-known coach-maker who patented his invention in 1805. The introduction of iron rim brakes in 1690 allowed larger teams of horses to be used to power the coaches. However, braking as we now know it was never a serious issue at the speeds of a horse-drawn coach and the brakes' major role was to slow vehicles descending steep hills.