

A HISTORY OF FREIGHT TRANSPORT PRIOR TO THE MODERN TRUCK

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Abstract

The paper provides a short world history of trucks from the earliest times to the present. It describes how people and animals provided the first sources of power. The paper then traces the development of load-carrying vehicles, from dragged branches, through to sledges, to wheeled vehicles. It describes and defines the load-carrying capacity of the various transport modes. It emphasises both the importance and uniqueness of the invention of the wheel, and then of the axle which led to the development of carts and wagons and then of steerable wagons. Despite these inventions, the paper notes that for most the history of civilisation, transport of freight by land was slow and inefficient. The factors which caused this to change arose as a consequence of the Industrial Revolution – better roads, the power of steam and then of internal combustion and the effectiveness of pneumatic tyres and well-designed suspension systems. The paper also describes the often futile attempts to regulate and control the damage caused by trucks.

Keywords: Truck (lorry), Animal, Power, sled, Wheel, Axle, Cart, Wagon, Industrial revolution, Roads, Steam power, Internal combustion, Pneumatic, Suspension, Regulation.

Résumé

Cet article retrace l'histoire des camions dans le monde depuis les débuts jusqu'à aujourd'hui. Il montre comment les personnes et animaux ont fourni les premières sources d'énergie. Il trace ensuite le développement des véhicules de transport de marchandises, des branches traînées et traîneaux aux véhicules à roues. Il décrit et définit la capacité de transport des divers modes. L'importance et l'originalité de l'invention de la roue est mise en exergue, puis de l'essieu qui a permis de développer des charrettes puis des chariots et ensuite des chariots dirigeables. Malgré ces inventions, pendant la majeure partie de l'histoire de la civilisation, le transport terrestre de marchandises est resté lent et inefficace. Les facteurs de progrès sont nés de la révolution industrielle – de meilleures routes, l'énergie de la vapeur puis de la combustion interne, puis l'efficacité des pneumatiques et des mécanismes de suspensions. L'article cite aussi les tentatives nombreuses et infructueuses pour réguler et contrôler les dommages induits par les camions.

Mots-clés: Camion, poids lourd, animal, énergie, traîneau, roue, essieu, charrette, chariot, révolution industrielle, routes, énergie de la vapeur, combustion interne, pneumatique, suspension, réglementation.

1. Animal power

After the creation and widespread application of footpaths, which are extensively discussed in *Ways of the World* (Lay 1992), the world's second major transport development was the use of animals, initially as beasts of burden and subsequently for pulling ploughs and sleds. The invention of the wheel was a much later development.

When freight first had to be moved, human hands, shoulders, hips, and heads were all gainfully employed. When the capacity of the unaided human was exceeded, the solid stick was the obvious tool to use, first to transfer the load to the shoulders and then to allow it to be shared as a yoke between two people. For less coherent loads, the technology expanded to include wicker baskets hung from the shoulders by rope or carried on the head. Such people-powered freight techniques are still in quite effective use today in parts of Asia and Africa. Experienced porters can carry 25 kg whilst travelling at 25 km/day. For shorter distances, loads of about half body-weight are common, and peak loads over very short distances can exceed 175 kg. The Chinese have used labourers carrying slings and bamboo poles to move loads of up to a tonne distributed at about 25 kg per bearer.

When the loads to be carried demanded greater strength or power than could be supplied by humans, the humans innovated by using their domesticated feed animals as beasts of burden, transferring the wicker baskets from human shoulders to the backs of cattle to produce the first pack animals. The domestication of large animals probably occurred about 7000 *B.C.*, initially to provide humans with a secure source of food. Their use to provide transport power was a convenient secondary development. For most of its history the world's roadway system has operated with domesticated animals as its sole source of motive power. Humans, cattle, onagers, donkeys, asses, dogs, goats, horses, mules, camels, elephants, buffaloes, llamas, reindeer and yaks are some of the species that have found useful transport employment

Pack transport took a step forward in about 3500 *B.C.* when the domesticated donkey came out of Africa. From that time forward the pack animal has been an unobtrusive but vital part of our transport operations. For example, from 2000 *B.C.* organized pack animal convoys operated in the Middle East. The early packhorse could carry up to 50 kg in two baskets but, by the end of the Middle Ages, breeding and loading improvements meant that a packhorse could carry about 120 kg, or a third of its body-weight, for up to 25 km. Similarly, donkeys could carry about 75 kg, mules 100 kg, and camels 175 kg. Despite these improvements, the role of the pack-animal was clearly limited by its load capacity. To overcome this restriction, long strings, or *drifts*, of up to fifty packhorses tied tail to nose worked many scheduled freight routes, with regular packhorse services operating in Europe from the fifteenth to the nineteenth century, often on their own separate packways. They were a major means of land transport.

As agrarian societies expanded, there was a growing need to move produce from fields to storehouses and processing areas and, later, to market. This demand could not be met by simply carrying the load on an animal's back. A breakthrough in freight technology was required. The potential for this breakthrough had arisen in about 5000 *B.C.* when the castration of domesticated cattle was found to produce an excellent power source in the ox, which could haul horizontal forces that were between four and ten times greater than the vertical forces that it could carry on its back. This development was probably driven more by the needs of agriculture than of transport and the first hauled device was probably the plough,

beginning as a hooked branch or log that was dragged across the ground, creating useful furrows. For both power and ease of harnessing, oxen worked in pairs, connected to either side of the plough log by a wooden crossbar yoke. Oxen were relatively easy to harness in this manner, as they pull from their prominent shoulders and humped backs.

It would not have been long before the cattle-harnessing technology developed for ploughing led to the thought that the same harness and crossbar yoke coupled to two dragged logs, rather than to one, would provide a platform for load-carrying, sometimes called a *travois*. In the simplest form the front of the load platform is carried on the animal's back and the rear slides along the ground. The next development was the sled, which was a flat platform that was dragged along the ground. This required a more elaborate construction and a new type of harness. However, if it operated over smooth surfaces with a friction coefficient of under 0.10, it could carry a greater load than could either the travois or pack horse. The sled is still used for freight transport in parts of the world. There is evidence of sleighs in use in 6000 *B.C.* As ice has a low friction coefficient, sleighs require little haulage force and therefore need a simpler technology and less power, as reflected in the common use of dog teams. By about 5000 *B.C.* castrated cattle had become the first work-horses of the road.

2. Invention of wheeled transport

The next stage of transport development was probably associated with the enhancement of the sled and travois. Small rollers between the pole ends of the travois or under a sled would have usefully reduced the dragging friction. A number of societies used such devices which were commonly called truck or truckle carts. Whether these transport issues were the demands that led to the invention of the first wheel remains a matter of conjecture. Early wheels were also used for pottery, and perhaps the original motivation for the invention was production rather than motion. Nevertheless, it does appear that the wheel was invented in Middle East in about 5000 *B.C.* The oldest known vehicle wheel comes from the southern Russian steppes and dates from about 3000 *B.C.* The uniqueness of the invention is evident in that, until Columbus reached the Americas in 1492, none of the relatively advanced civilizations there had developed practical wheeled vehicles. Nor was the wheel developed indigenously in Southeast Asia, southern Africa, or Australia

An important next stage was the use of an axle to join two wheels together and thus give vehicles increased stability and load capacity. By about 3000 *B.C.* a variety of vehicles in the Middle East had begun to make practical use of the wheel. The first were two-wheeled carts based on an A-frame with the draught animals at the apex and the axle forming the cross bar of the A. A major break-through was to carry the forward vertical component of the load being hauled on the ox's back rather than on its shoulders. This change increases haulage capacity by about 50 percent, but eluded many civilizations. Cumbersome four-wheeled wagons followed in about 2500 *B.C.* Their weight meant that only oxen were able to provide the necessary haulage power. The initial wagons had a single hauling shaft as they were based on precedents established for yoked oxen.

Wagons without a steerable front axle were relatively simple and cheap, but created major problems, particularly when faced with sharp curves or when their wheels became caught in deep ruts. The development of generally useful wagons and carriages therefore required steerability to be developed as the next stage in the invention sequence. This was achieved in about 500 *B.C.* (although some commentators put the date as early as 1500 *B.C.*) with the production of an axle capable of swiveling about a vertical axis. Such vehicles can be readily

detected in accurate drawings because the front wheels had to be small enough in diameter to pass under the floor of the vehicle. The technology did not spread rapidly. There were only a few steerable wagons in fourteenth-century England, and they were not widespread until the seventeenth century.

Harnessing animals in line was common by about 100 *B.C.* and dramatically increased the size of the payloads that could be hauled. However, it was not widely used by the Romans, thus restricting them to two effective animals per heavy vehicle and severely limiting their haulage capacity. Roman harnesses also tended to choke animals during a hard haul and did not permit the animal to slow the vehicle on a downhill slope. During this period, horses were also being used for haulage. However, hauling requires a much more sophisticated technology for the horse than for the ox, because the horse pulls from forward of the shoulder. Under load, the breast band and neck strap of a yoke tend to press on the horse's windpipe, causing choking and suffocation. An effective horse harness therefore needs a carefully structured, padded collar resting on the horse's shoulder in order to prevent harness pressure on the windpipe. It also works best with a pair of shafts, rather than a single shaft. The introduction of such a harnessing arrangement increased the haulage capacity of the horse fourfold. Nevertheless, its application was not widespread, preventing many communities from using the horse to its fullest. It did not arrive in Europe from central Asia until 750 *A.D.*, well after the Romans. All this had major transport implications. A pair of horses that should have hauled three tonne could only manage 0.5 t with Roman carts and harnesses.

Horses became more commonplace in the eleventh century and gradually began to supplant the ox. Many factors influenced the decision as to whether horses or oxen were to be used for haulage. Both had about the same haulage capacity, but horses could make 30 km cart trips each eight-hour day, whereas oxen could only travel half that distance. The ox produces about the same tractive pull as the horse but at only about half the speed (2 km/h rather than 4 km/h), so its power output is halved. Oxen were more difficult to organize but could keep going over more days, required less water, were easier to feed and harness, were more able to manage difficult terrain, and were less likely to be bogged. Their hooves were more durable than those of an unshod horse, however this last advantage began to disappear with the development of the horse shoe in 700 *A.D.*

Thus the major land-based movement of freight in the last millennium has been by cartage, due mainly to the pack animal's low 50 kg load capacity. This meant that about twelve packhorses were needed to carry the same load as a single horse and cart. In the eleventh and twelfth centuries carts rather than wagons still predominated in Europe. By the thirteenth century, as the improved harnessing technology spread, both carts and wagons were in common service. Thus, during the fourteenth century transport had a profound effect on the countryside, changing farming from a subsistence life style to a market-oriented industry. Professional carriers also became commonplace, providing a remarkably economical service which only added about ten percent to the cost of a typical commodity for hauls of 80 km.

Most citizens of the fifteenth century still regarded wheeled vehicles as external interlopers. However, when Queen Elizabeth travelled to Warwick in England in 1572, her baggage was conveyed in six hundred carts. By 1599 regular cart-based freight services were operating between London and the Ipswich cloth industry. Similar scheduled services expanded rapidly over the next forty years, although the technology was only selectively available. Carts were not introduced into the more remote parts of Devon, Wales, and Scotland until the nineteenth century. In such areas, freight movement by dragged sleds remained common as long as

roads remained poor. Within urban communities much freight was moved by wheelbarrow, a device which also found some application in intercity transport. The growing use of cart and wagon was not met with universal acclaim. In 1669 Courtney Poole urged his colleagues in the English Parliament to ban all carts and wagons, because they "discouraged navigation". The vehicles also severely damaged many roads, provoking strong administrative reactions and ingenious technical rejoinders.

The large four-wheeled wagon was primarily a German development. In the mid eighteenth century, German settlers on the Conestoga Creek in Pennsylvania produced the famous Conestoga wagons with their distinctive bright blue bodies, red trim, and white canopies. Weighing a little over 1 t, the wagons were hauled by four to six horses travelling at about 3 km/h and had a capacity of between 3 & 6 t, depending on the road surface. A useful feature was a boat-shaped floor, which prevented cargo from being displaced during a rough ride. By the 1850s the loads that could be carried on conventional vehicles ranged from 2 t on a two-wheeled cart to 8 t on a four-wheeled wagon. For up to eight hours of travel at 5 km/h, a properly harnessed horse produced a pulling force of one-tenth of its weight when travelling over good foothold. Thus a half-tonne horse produced a pulling force of $0.5/10 = 0.05$ t, which was equivalent to the output of five men. A poor surface has a coefficient of friction of about 0.05 so a typical load capacity for a range of highway conditions was $(0.05 \text{ t})/0.05 = 1$ t/horse. For long distances the load capacity was closer to 0.5 t/horse, and this was also the value used for battlefield conditions. Roman vehicles and horses had had a load capacity of only a 0.3 t/horse, even over relatively good surfaces.

Over a day, a horse produced a constant energy output, no matter how it was worked. The well-known horsepower unit was first calculated by James Watt and was based on the assumption that a strong 0.75 t horse travelling for a short time at 3.7 km/h could pull a cart with a tractive force of one tenth of its weight, i.e. of $0.75 \times 0.1 \times 9.8 = 735$ N, which gives a power output of $735 \times 3.7/3.6 = 746$ W, or one horsepower. Over a full day, the same horse can only produce about 500 W.

Its low load capacity made freight transport by wagon inordinately expensive for long-distance hauls and so, for much of history, the boat and barge have been by far the more effective means of moving freight. Even when Rome was at its peak and at the hub of its enormous road system, it preferentially received its food supplies by water. In the twelfth century, Frederick I of the Holy Roman Empire declared the Rhine to be the king's highway. An estimate from 1818 was that it cost as much to haul 1 t of payload 50 km by road as it did to move it across the Atlantic by ship. Relative costs to move 1 t through 1 km in the nineteenth century were downriver barges, 1; canal barges, 5; rail, 10; and road, 30.

3. Wheel Loads

The load that a vehicle can carry is of vital interest to the vehicle operator. However, for the road manager the key question is the load and the pressure that each individual wheel applies to the pavement. In addition, to reduce both its weight and its rolling resistance over good surfaces, the hauler needs a narrow wheel with a narrow tyre, whereas the road manager requires a large tyre-pavement contact area to protect the pavement. Thus, the joint questions of the maximum load to be carried by wheels and the required width of tyres have long been key points of debate in road management, both to prevent road damage and to provide a basis for charging users based on the wear and tear that they cause. Nevertheless, over time and at

all levels, there are numerous and continuing examples of high-level debate and decision-making hopelessly confusing issues separately related to total load and axle load.

The earliest recorded load limits date from 50 *B.C.*, when the Romans restricted vehicle loads to about 250 kg. The situation slowly evolved and in 438 *A.D.* their Theodosian Code set the limits at 750 kg for an ox-drawn wagon, 500 kg for a horse-drawn wagon, and 100 kg for a cart. The pace of change did not quicken, for in 1622 England prohibited loads greater than 1 t being carried on any vehicle operating during the winter. A significant improvement in road conditions then led in 1765 to the maximum permissible load carried on English roads being raised to 6 t. This remained a practical upper limit for many years. The wheel load limits in use in 1809 are given in Table 1. The illogic of these load limits giving a decrease in contact pressure as the width increased was recognized but ignored.

Table 1 - 1809 United Kingdom wheel load limits for four-wheeled vehicles.

Tyre width (mm)	Load per wheel (t)	Contact pressure (MPa)	Number of horses
50	1.0	4.0	4 (stage coach)
75	0.9	1.6	4
150	1.1	0.5	6
275	1.3	0.6	6 (conical wheel)

Traditionally, when load limits have been widely promulgated, they have been just as widely flouted. The Theodosian Code restricted the number of animals that could be used to haul a vehicle because a horsepower approach was far easier to police and measure than was a load limit. In 1508 the method was adopted by the city council of Paris, banning wagons drawn by more than two horses. In 1629 an English Act prohibited more than five horses from drawing any vehicle; after forty years the horsepower limit was relaxed from five to seven. A similar alternative was to limit the number of wheels. For instance, from 1622 to 1661 an English law decreed that only two-wheeled vehicles could be used on English roads. The main consequence of the two-wheel law was to produce grossly overloaded carts.

Another technique was to limit tyre width. An English Act of 1662 required tyres to be at least 100 mm wide. This act was soon suspended and then repealed in 1670 when it was found that the new wide wheels would not fit into many of the country's well-established ruts. The rut problem must have diminished, for the width limit was raised to 225 mm in the 1753 Broad Wheels Act, which additionally required 450 mm wide tyres to be used when very heavy loads were being carried. Protests led to an amendment two years later that permitted the use of 150 mm wide tyres for wagons pulled by fewer than seven horses. A subtle variation introduced in 1765 imposed lower penalties on wagons whose fore and aft wheels were staggered laterally so that they ran in different but adjacent wheel-paths. In 1767 vehicles with tyres at least 225 mm wide were permitted to be drawn by up to seven horses and those with 400 mm tyres to be drawn by any number of horses. The toll roads of the eighteenth and nineteenth century imposed higher tolls on narrow-tyred vehicles in an attempt to discourage their use.

A major effect of these regulations was to favour the use of broad-wheeled freight wagons using 400 mm wide tyres. These inefficient vehicles required teams of a dozen or so horses, effectively pulling loads of only 700 kg each. In England they were first used on turnpike roads, where they were granted five years of toll-free operation. Such vehicles were

commonplace for over sixty years until the final abolition of many of the tyre-oriented regulations in the Highway Act of 1835.

A closely related, and equally ineffective, eighteenth-century attempt to circumvent the wheel width regulations was the use of very large conical wheels that rolled and slid on the roadway. They were little more than narrow wheels legalistically disguised as broad ones to gain the broad-wheel concessions. The result merely demonstrated the distorting effect of wheel-control legislation, as the tapering meant that much of the contact surface had to be dragged rather than rolled along the road. A sometimes more constructive adaptation was the use of dished wheels to provide lateral strength and obviate the need for heavy spokes..."sometimes", because the adaptation was also used to evade the wheel-width laws by keeping the actual contact width small.

On poor surfaces wide tyres were used to permit easier passage of the vehicle, provided that enough motive power was available. Indeed, a few late eighteenth-century heavy wagons used great rollers rather than conventional wheels but it was rarely possible to make the rolling surfaces wide enough and the power sources large enough for the devices to be practical. Haulers thus had to find other ways to overcome poor pavement surfaces. One such alternative was the use of very large diameter wheels; 1.6 m diameters were common in 1800, although wheels of this size made it difficult to provide a steerable front axle. The basic principle followed over most of transport history has been to make the vehicle suit the road, with little attempt at adapting the road or the system to the vehicle. Sidney and Beatrice Webb in their comprehensive review in 1913 referred to events in the eighteenth and nineteenth century as an: "*interminable series of enactments, amendments and repeals--successive knots of amateur legislators laying down stringent rules.*" Direct policing of load regulations was not easy as quantitative load levels were not obvious to the eye and their direct control required some means by which they could be ascertained. The initial method involved winching the vehicle to be weighed off the ground and determining its weight by a system of steelyard levers and scales. Public weighing facilities were introduced into Dublin in 1555, "to eschew the loss to excessive and untrue tolls". In 1602 a toll on carts weighing over a tonne was introduced in Kent. In 1741, British turnpikes were permitted by law to charge extra tolls on loads over 3 t. The tax was strongly but fruitlessly opposed, with opponents pointing out that it would merely encourage more small carts. In 1744 John Wyatt invented the modern weighbridge platform and hence made weighing vehicles far more feasible. Not coincidentally, at the same time weighing devices were legalized and the rights to operate them were let annually, usually by public auction. The moves were clearly successful as in 1751 a further law made such facilities compulsory on turnpikes within 50 km of London.

In addition to overload due to the load on a single wheel, a further problem is that of pavement wear and tear due to frequent usage, even by traffic within legal load limits. Iron tyres were favoured by haulers because they not only permitted tyres and wheels to be narrowed but also lasted far longer than the timber alternative. However, road maintainers viewed them much less favourably because they abraded the road surface and produced high contact stresses. The problem was often worsened by the practice of driving iron nails with prominent heads into the tyre's running surface in order to provide better surface traction. In medieval times iron tyres were sufficiently common and damaging for a number of towns to prohibit their use. Subsequently, many cities had occasion to ban the entry of iron-wheeled vehicles.

At the beginning of the 20th century, many laws still existed requiring a millimetre of tyre width for each 10 to 18 kg carried. A typical formula was:

$$\text{width in mm} = (\text{mass carried in kg}) \times C / (\text{diameter in mm})$$

where the values of $C = 15$ for earth, 10 for macadam and 2 for paved roads approximated the strength of those pavements. However, at this time internal combustion (IC) trucks with solid rubber tyres were launching a new, destructive attack on road pavements. The problem was most severe in the United States where surplus trucks from World War I caused particular havoc. A major Bureau of Public Roads research program showed the great advantage of using pneumatic rather than solid tyres and recommended a higher maximum wheel load of about 4.5 t if pneumatic tyres were used, due to their greater area of contact with the pavement. Although European practice was to adopt a somewhat larger value, wheel loads themselves have remained relatively constant since those decisions in the early 1920s. This type of reaction is an almost inevitable result of having a road infrastructure that changes far more slowly--perhaps at fifty-year intervals--than the associated vehicle technology. The major increases in gross truck loads to around 100 t have been the result of adding more wheels and more axles to trucks, rather than of raising wheel loads. The number of passages of legally loaded wheels thus depends only on the total freight task.

The pneumatic tyre was introduced to make the bicycle a usable and useful tool. This in itself was important, but the key long-term effect was to overcome the millennia-old narrow wheel/high-contact-pressure problem. The pneumatic tyre allowed high loads to be applied to wheels in the knowledge that the tyre would spread the load over an area such that the contact pressure would approximate the tyre inflation pressure. A small calculation will demonstrate this. Wheels with solid tyres could carry loads of up to 2 t. Such loads are large enough to damage pavements, and the use of narrow tyres exacerbates the problem. For a 2 t load and a typical steel tyre width of 100 mm, the contact pressure between tyre and pavement is about 2 MPa. On the other hand, the modern truck wheel can carry double the load with contact pressures of only 0.7 MPa, and with far less impact than the solid wheel, thus significantly reducing the actual stresses caused in both pavement and vehicle.

In practice, the favourable load distributing effect of the pneumatic tyre was far more dramatic. Pavement engineering uses the concept of equivalent standard axles or ESA, to compare the damaging effects of various vehicles. The ESA value of a particular wheel configuration is the number of passes of the standard axle that would do equally as much pavement damage. Table 2 gives some damage equivalents for the beginning of the 20th century, when two dramatically different transport technologies were overlapping. The advantage of the rubber pneumatic tyre is very obvious. The early trucks were too heavy for the first generation of rubber tyres, which could only carry about 0.5 t. Trucks therefore ran predominantly on solid steel tyres until reliable solid rubber ones became widely available in 1910. The solid rubber tyres were only marginally less damaging to the roads than were iron tyres. Michelins produced the first pneumatic truck tyre in 1912, but a number of difficulties were encountered. Technological success came about in 1916 with tyres using cord rather than canvas as reinforcing, but these did not make a significant on-road impact until the late 1920s. Suspensions were developed mainly and initially to provide passenger comfort, but have also reduced the dynamic and out-of-balance loads produced by trucks (Lay 1998).

Table 2 - Damage equivalents per trip for various wheel types, normalised for type 4.

	Vehicle type	Equivalency based on type 4
1	Unharnessed animal	0.2
2	Single animal harnessed to a vehicle with pneumatic tyres	0.2
3	Single animal harnessed to unloaded vehicle with steel tyres	0.5
4	Single animal harnessed to a vehicle with steel tyres	1.0
5	Car unable to travel at over 30 km/h	1.0
6	n animals harnessed to a loaded vehicle with steel tyres	n
7	Car able to travel over 30 km/h	3
8	Truck with steel tyres	25
9	Steam traction engine with steel tyres	36

Horse-drawn delivery vehicles with iron tyres were still in use in many of the major cities of the developed world in the late 1940s, and an Australian vehicle census in 1945 counted some 15,000 operating horse-drawn vehicles. In many countries much freight is still carried in hard-tyred animal-drawn carts and wagons. In 1986 India had some 15 million animal-drawn vehicles, only 7 percent of which had pneumatic tyres.

4. Internal combustion (IC) at work

With the development of steam technology, the first mobile steam engine for agricultural and construction use was produced by Ransomes in 1842. By the 1860s such machines were quite common and came to be known as steam traction engines. They were easily recognized by their large and elaborate wheel systems. They were occasionally used for road haulage--a practice which continued in Britain until the 1930s. In good conditions they had a maximum speed of about 10 km/h. In the 1870s Rookes Crompton used rubber-tired steam engines to operate an Indian transport system based on trucks pulling long strings of wagons. This road-train technology was transferred to many other countries, with Daimler-Renard producing an IC version in 1903. It had a top speed of about 10 km/h. This road-train technology was transferred to outback Australia which now has an extensive system with individual road-trains carrying 100 t loads at speeds of 100 km/h on public roads.

Daimler built the first IC truck in Canstatt in 1891 by slinging an engine under the tray of a Daimler Riemenwagen chassis wagon. He began selling the vehicles in 1894 and still had the bulk of the market in 1900. The invention was not universally well received. According to one contemporary commentator, the IC truck "barked like a dog and stank like a cat". Thornycroft produced the first articulated truck in 1897 and the fifth-wheel semi-trailer was introduced in 1911. As in many other parts of this story, the needs of the military played a leading role in the development of the truck. The French began using IC vehicles in military manoeuvres in 1897 and the first use in battle was in the Boer War between 1899 and 1902. Their future military usefulness was recognized in many countries. The governments of Britain, France, and Germany paid citizens an annual subsidy of about 20 percent to purchase and maintain trucks suitable for military use. By 1914 the French army possessed some 6000 IC vehicles. Many vehicles were also requisitioned for military use and provided further incentives for truck development. For instance, in 1917 the United States began manufacturing a standard military vehicle called the Liberty Truck. The one- and 3-tonne versions became the most widely used trucks in the War. Disposal of the surplus war trucks

was not a simple matter. The U.S. government sold many at quarter price to European governments, the post office used 5,700 as mail carriers, and 24,500 were given to state highway authorities for road construction. The trucks thus played a major role in developing the American road network.

These post-war government sales of cheap trucks and the return to civilian life of many ex-farm boys whose only usable skill was their ability to drive and maintain the new trucks provided a major impetus toward the complete motorization of post-war communities. General John Pershing returned from the war convinced of the future military importance of trucks and determined to further demonstrate their effectiveness. To this end, in 1919 he organized a convoy of seventy-nine military trucks and almost three hundred soldiers, including a Lt. Col. Dwight D. Eisenhower, who travelled from Washington to San Francisco, initially following the route of the National Road. The convoy took fifty-six days and averaged 80 km/day.

The rapid increase in truck traffic after 1918 had had a dramatic negative impact on road systems. The U.S. truck industry responded with the slogan “Build the Roads to Carry the Loads”. One constructive consequence was the establishment of the Highway Research Board. The truck-makers, in response to public pressures, agreed to voluntarily limit truck capacities to 7.5 t to protect future roads. Nevertheless, as trucks moved from solid rubber to pneumatic balloon tyres in the 1920s, road-makers came to realize that it was indeed cheaper to build roads for the new IC trucks than for the old horse-drawn carts and wagons. A regular traffic count on the London-Folkestone road showed that the percentage of freight moved by truck rose from 41 percent in 1911 to 95 percent in 1922. The major impact that trucks were having on the railways is demonstrated by a 1923 report of a New York railway company, which stated that “a large part of the high classification shipments such as thread, machinery and brass parts, has been transferred to motor trucks.” Trucks captured much of the freight market, yielding to rail and canal only on long bulk hauls and to air only on high speed long distance delivery. Private enterprise flourished in the truck industry.

5. Conclusions

The paper has shown how the means of transporting freight have developed over many millennia to meet key human and market-place needs. Over time, the slowly-changing road infrastructure has provided ongoing constraints on vehicle size and on vehicle-pavement interactions, particularly as expressed by individual wheel loads and contact pressures. Wheel loads have changed very slowly and most increases in load-carrying capacity have been achieved by increasing the number of load-carrying wheels. Trucks have become longer, but not wider nor higher. The introduction of improved suspensions and of pneumatic tyres has also made the task more manageable.

6. References

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