# HISTORICAL TRANSPORTATION DEVELOPMENT

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## Contents





## Summary

In the early 1800s, England was the venue of the emergence of the modern maritime and rail modes/systems. These built on the technological and institutional features of eighteenth century canals, docks, ships, tramways, and roads. The steam engine, iron and then steel, and the telegraph also served as ingredients or building blocks in the recipes

for the modern modes. The recipes are illustrated by Stephenson's contributions to railroad building and Brunel's contributions to steam-powered iron ships. Their work and subsequent developments illustrate the roles of market niches, design, innovative people, and robust institutions in the evolution of new systems.

The modern rail and maritime modes were diffused worldwide by about 1920. In addition to increasing service areas and utilization, there were service improvements as the modes honed their technologies, concentrated traffic on routes, and specialized their services.

Diffusion took place in both urban and rural areas. Urban areas served as terminals for maritime, inland waterway, and rail services. Electric streetcar service expanded beginning in the 1880s. Diffusion also took place in varied policy environments, as contrasts among statist, capitalistic, and mercantilistic behaviors indicate.

Airplanes, trucks, and automobiles emerged in the early 1900s as workable designs and markets appeared for them. The diffusion of aircraft services accelerated in the 1930s followed by a second surge of growth beginning in the 1960s. The diffusion of automobile and truck services began earlier. Around the turn of the twenty-first century, services are approaching saturation in many markets.

The modern modes emerged in the 1800s and 1900s and are the products of those times. Twenty-first century innovators and policy makers have the choice of concentrating on further constraints and refinements of these modes or using them as building blocks for modes more suitable to the present and futures.

## 1. Introduction

The main tasks for this overview of transportation development are the presentation and interpretation of information about the unfolding of the transportation systems. What processes have been at work? What explains the similarities and differences among systems and regions? These big questions are eased by examining how systems are the products of experiences. The immediately following paragraphs summarize early experiences and touch on life support systems, sustainability, and social developments.

After examining their immediate precursors, this article discusses roads, airports, trains, trucks, buses, ports, automobiles, firms and agencies, and other features of modern transport infrastructure. Although the cost, quality, and mix of services vary among regions, some kind of service is available most everywhere. Indeed, the situations in different nations have many similarities, as do varying urban and rural settings.

### 1.1. Early Transportation Developments

There has always been trade, human interaction, and transport, for almost no society has ever been purely subsistence in character. Expanded trade and political pressures have pushed for improvements, and there have been surges of transport developments associated with the expansion of empires. Overland and river routes served the trade of Mesopotamia five millennia ago. Roman hegemony was supported by Roman roads just as Persian, Chinese, and New World rulers were supported by their roads. Not much later the grain trade in the Mediterranean flourished along with Orient–European linkages. Later, Iberian, Dutch, French, and English empires were based on transport and trade.

Thoroughgoing changes in transportation accompanied the evolution of the modern world. A wave of these were seen in Europe in the centuries just before 1300, when a network of trade centers emerged to replace feudal economies. An explanation for change was the Crusades, which broke many feudal barriers to individual movements and trade. Charlemagne's wandering armies, which plundered here and there between the planting and harvesting seasons, illustrate that movement had increased by the ninth century as barriers were reduced, often forcefully. Charlemagne's wandering also illustrates how ideas move easily, for in addition to ill-gotten loot, Charlemagne returned with ideas about building bridges and large buildings. By the eleventh century, road transport had adopted existing technologies including iron shoes and harnesses for draft animals, swiveling front axles for wagons, and bridge building techniques. But because road transport costs were high, coastal and river transport served most movements. Europe was advantaged by its geography as a well watered peninsula of peninsulas.

There were improvements in navigation technologies that aided the ocean trades. Ports were chartered by governments, mechanical aids to material handling evolved, and oceangoing ships designed mainly for merchant purposes appeared. Portuguese Atlantic ventures began in the 1430s. River improvements began as did canal construction. The 1648 Treaty of Westphalia increased access to the rivers of Germany. Eventually, extensive canal systems threaded through Europe and these were followed by improved road systems with toll roads in many places.

Another surge of development began around 1800 when steam engines were applied to water and land transportation. Beginning about 1900, developments building on those modes began serving the modern world with other varieties of air, marine, and land transportation.



### 1.1.1. Integration and Coupling

The recipes for advances seen in past centuries continue today. The pre-1300 advances integrated resources and markets. Advances were achieved by decreasing barriers to movements and by expanding and improving networks. Institutional and political arrangements aided trade, for example, alliances such as those among the cities of the Hanseatic League in the Baltic region between 1200 and 1400. Indeed, the Hanseatic League has been termed the first of the multinational corporations. The integration of resources and markets increased the variety of consumption options and the varieties of inputs and markets available to producers.

In addition to continuing such integrating improvements, the centuries prior to 1800 saw improvements in technologies that coupled different modes, for instance, ports coupling land and sea modes. In addition to facility improvements, the movement of money and information demanded by trade were enabled by advances in banking and currency exchange. Instruments such as bills of sale and letters of credit supported market transactions. Bills of lading and waybills were evolved to document what was shipped and how it was to be moved. Stock companies financing ships and cargo and insurance carriers emerged in the maritime trades.

Systems of tariffs were created, and warehouse, freight forwarding, and freight consolidation actors began to aid transactions among shippers and receivers of goods.

### 1.1.2. Development or Revolution?

These developments may be thought of as revolutions when the relations of transportation and social and economic development are considered. Improved access to resources and markets increased the choices available to producers and consumers. Beyond that, there was improved access to the worlds of ideas and knowledge, a point often noted in discussions of the Crusades. Ideas are light baggage and they move wherever there is travel and trade.

There were certainly surges of advances. Should they be thought of as revolutions?

Improvements in knowledge and access to markets enabled the specialization of production. Brussels became a center for cloth production, England exported wool and leather, and the Baltic grain trades flourished. Trade supported the great cities of northern Italy. By the twelfth century, Venice and Florence each had achieved populations of about 100°000 and Paris soon grew even larger. As trade and allied services such as banking grew, London, Amsterdam, and other port cities grew.

Increased trade and contact with information and ideas of all sorts brought about new expectations and aspirations for individuals and changed power relations. Eventually merchant, artisan, and other classes began to gain power and push aside royalty and the church, as well as the large land-holding class. New ideas including those of science and engineering began to circulate and concepts of democracy and freedom bloomed.

It is fair to say that transportation advances, working with other advances, such as the printing press, enabled thoroughgoing changes: revolutions. It is just as important to say that transportation advances were conditioned by social environments and markets, as is the case for all technologies.

Finally, it is important to note that this process took decades and centuries and that social upheavals accompanying the changes were real and often bloody. As is the case today, change was often resisted by those displaced or otherwise affected by technological changes and advances.

## 1.2. Transportation and Other Life Support Systems

Although the early record is blurred by lack of data and differences among regions, there is no doubt that societies faced difficult conditions time and again. For instance, plagues and highly variable weather occurred in the 1300s and 1400s. Later, a “Little Ice Age” extended for two centuries followed by warming beginning in the late 1800s. Famine and disease took their toll on population growth. Populations declined in some periods, and settlements disappeared in some areas. Wars and social strife surged throughout Europe, and the great ages of exploration and conquest elsewhere brought their varieties of tears and cheers.

How well did transportation serve society? It enabled the growth of cities and many other things, and it served well enough that demand continued to grow. Its failings, such as not transporting food to distressed areas in times of famine, may have been partly due to lack of system capability, but seem largely a matter of lack of social organization and will, a situation that, although moderated, continues today.

Some ask if transportation is sustainable. It was during the period reviewed in this article, for it survived in spite of adversarial conditions. There were problems. Wandering Goths destroyed Roman road services. There were decades in which services to Iceland and Greenland were blocked by storms and ice, the freezing of the Baltic Sea caused disruptions, and the farmland required to produce feed for horses competed with food production. (Roughly, 1 horse required 4–6 acres, or 1.6–3.2 ha, for hay production.)

Another question is how well transportation will serve in the future. As in the past, today's systems are the building blocks for future systems. The question is whether we have the ability to use the building blocks wisely.

### 1.3. Scope of this Discussion

The following discussion is an overview of the development of services and expands on the precursors to the modern modes, treats the emergence of modern rail and marine services, comments on regional and national differences in development paths, and highlights repeating historical themes and recipes when discussing recent developments. To begin, the major systems/modes will be reviewed in the context of English and European experiences. It will be seen that the modes are products of experiences and pragmatic decision making.

This discussion seeks generality and tries to ease the burden of treating the details of changes by giving snapshots of events such as the emergence of steam ship services. These snapshots are used as examples or metaphors that mirror the logistics of development.

## 2. Building Blocks for Modern Systems

The modes or systems (the words will be used interchangeably) emerged sometimes in a serial fashion and sometimes more or less in parallel. The recipe for emergence was much the same everywhere and for each mode, although recipes and outcomes were tempered by differences in geographical and political circumstances. Europe, and England in particular, was the venue for early developments, and this is the reason for the English–European emphasis in the discussion to follow.

Looking around Europe just before the industrial revolution, say in the mid-1700s, the Atlantic was a pond connecting the ports of the Old and the New World. Ocean and coastal ships served ports and penetrated inland to heads of navigation. Roads and trails served overland travel and improvements were underway, especially in France. Already, canal service was available in Italy, France, and the Netherlands, and rapid canal construction would soon begin in England, Russia, and elsewhere.

The modern systems emerged from the services available in those years, which served as building blocks for the modern ones. Their stories are very rich but briefness is required here.

### 2.1. Rivers and Canals

The low value of many of the commodities moved and the high costs of land transportation urged movement of watercraft as far inland on rivers as practicable. But river navigation posed some physical difficulties. There were large tides, low water levels during some seasons, and dredging needs. There were use conflicts. Mill operators resisted releasing water from their dams for navigation. Owners with riparian rights claimed tolls for improvements or for the use of embankments for pulling boats or for goods transfer between boats and land transport. They also sometimes resisted river improvements.

There was government involvement early on. The City of London started developing the River Thames in 1179, and by 1500 several city corporations had been given river development authority. Upstream, the Crown gave development authority to local landowners who put forward specific development and toll schemes.

The river experience yielded the first institutional form for canals, and there were carryover technological experiences. River development utilized dredging, flashboards, and a few locks. The flashboard system required a good water supply as boards were removed and floodwater raised boat levels, while canals could not be so wasteful of water. Lock technology, in particular, could carry over directly as could dredging technology. Also, construction methods improved. William Smeaton, later a famous canal engineer and recognized as the father of British civil engineering, obtained his first experience on river projects.

The beginning of the English canal era was marked by the Duke of Bridgewater's 7.5 mile (12 km) canal from coal mines on his estate at Worsley to Manchester. Construction began in 1759, and the canal opened 6 years later. Bridgewater's canal had some interesting technological features. It tied into his mine drainage scheme, and the boats ran into the mine for loading. Although the canal could accommodate larger boats, the within-mine operations kept the beam of the boats to about 7 feet (2.2 m); they were 50 feet (15m) long. In order to hold water, the canal was lined with puddled clay, and to avoid extensive lock construction, an aqueduct was constructed over the River Irwell.

This canal caught the imagination of the public. As a financial success it motivated developers and investors. It served as a model for subsequent construction and about 3 000 miles (4 800 km) of canals were opened in the next 90 years. Waves of canal building followed in Europe and North America. French and US systems expanded to about the size of the English system.

There was a flurry of inland navigation acts between 1759 and 1794. Most of these were for narrow canals, using the 7 foot (2.2 m) beam boat design from Bridewell's canal. Adoption of the 7 foot boat kept construction costs down and saved water, a problem for many canals. Boats ran 70 feet (21.4 m) in length, could carry about 30 tonnes, and could be hauled by a horse or mule moving along a towpath alongside the canal. Canal building yielded much experience with earth moving, lock structures, bridges, aqueducts, tunnels, etc. Firms were organized for contract construction and engineers, managers, and laborers gained experience.

Although navigation acts were private acts, the policy and institutional aspects of canal building began to fall into a pattern. Canal companies were organized and issued stock. There was carry over of rights of use from roads, and acts began to require that anyone could operate a boat if tolls were paid. Companies emerged to offer canal plus pickup and delivery services.

Where the terrain was difficult or water was in short supply, inclined planes were constructed. Building on the fringe of the feasible created a need for suitable technologies, and some small tub canals were constructed. Commodities were moved in trained, 6–10 tonne "tubs." Each could be moved by a horse on a near-level tramway, and they could be handled relatively easily on inclines.

By about the second decade of the 1800s the era of canal building in England was over. In part, the system was "built out" in that all the feasible canals had been built. Also, rail competition had entered the picture.

The modern modes owe much to canals. They demonstrated the payoffs from capital intensive transportation improvements. They increased construction know-how and institutional experience. They also provided management, financial, and operating experiences and related institutions. There was also important learning by the public about investment opportunities and off-system developments induced by transportation improvements.



### 2.2. Roads

In England, as elsewhere, local roads and trails were everywhere available. In the very early days they were alignments and paths that shifted depending on seasonal stream flow and the quality of footing and grades desired by walkers, packhorses and mules, carts, and cattle drives. The English local parish road system involving statute labor began to be strained in the 1500s because of the growth of through traffic (roads became no longer a local matter) and the breakdown of the manorial organization of life. Bridges were a technical and fiscal problem, and the 1537 Statute of Bridges was the response. Next, there was the Highways Act of 1555, resulting in the election of surveyors to plan and supervise the four days of statute labor per year, soon raised to six days. With revisions, this system served until the 1830s. Surveyors were given powers to requisition materials, and parishes were empowered to tax for road improvements. Labor could be hired.

However, the mismatch between regional travel and local responsibility remained, and policy had not responded to technical questions such as how to best build roads. Radical changes began to emerge as local governments attempted to deal with those problems. Some started charging tolls on heavy vehicles to raise money for repair, others set maximum weight limits for vehicles. Local governments worked together to develop toll and road programs. There were efforts to increase the widths of wheels on large vehicles. In the meantime, traffic of all types continued to grow, and stagecoaches and mail wagons emerged in the early 1600s. Packhorses and mules were less and less often used and wagons increased in size and weight.

The bridge problem became acute. The 1537 Statute of Bridges did no more than put the responsibility for bridge maintenance on the parishes, and it had few “teeth” in it. Technical problems included the narrow widths, unsuitable timber construction, and steep access and egress.

The stage was set for considerable revision of highway policy. One revision allowed and encouraged turnpike developments, beginning about 1650, but taking off about 1700. Another was a restatement of the responsibilities of the parishes.

The parishes first. Policy emerged in the 1760s and 1770s with a rationalization tone. There was effort to define the technologies needed: for example, town access roads were to be at least 20 feet (6 m) wide. Efforts to control weights and vehicle configurations expanded. For instance, wider wheels were required when more horses were used, for example, six horse teams hauled wagons with wheels six inches across. Cross routes and little used routes could be abandoned. Taxes were graded so that those who used the roads the most paid the most. Ills were dampened, but poor construction, drainage, and bridge problems remained.

### 2.2.1. Toll Roads

The toll road or turnpike was the answer. Such roads predated the canal era, as mentioned, and early ones (e.g., in the 1600s) were ad hoc extensions of the parish system in that several parishes would work out a joint project using the surveyor and obligated labor arrangement.

Although development of turnpikes was slow in the first half of the 1700s, a pattern of development had emerged by about 1750. The new development was trust organized and town centered. The effects on roads of traffic to London and provincial centers required action, and successful acts and schemes prior to about 1750 yielded a map of rather disconnected, urban-centered routes. By then there were 143 trusts managing about 3 000 miles (4 800 km) of roads. Later acts then filled in the map and by 1830, there were more than 1 000 trusts and 20 000 miles (32 180 km) of roads.

Road trustees were local men and women of substance. Enabling acts specified powers, accounting and meeting requirements, and provided for posts of treasurers and surveyors. The early pattern was for tolls to be collected at gates (by toll farmers), and reinvested in repair after expenses were met. Soon, mortgage funding guaranteed by gate income became common.

Toll schedules were very complex. They reflected geographical equity, the principle that those who occasion costs ought to pay, and attempts to protect roads from damage. The latter yielded high charges on excessive loads and on vehicles with narrow wheels.

The technical view was that roads needed protecting. At the national level, the General Turnpike Act of 1773 contained 28 clauses relating to wheels, weights, etc.

Robert Telford became involved with the technology of road construction in 1803 when Parliament considered the problem of roads in the highlands of Scotland. A development scheme was initiated where Parliament would pay one-half of the costs if local politicians would propose schemes and pay the remaining costs. Telford surveyed needs and developed geometry, pavement, and drainage engineering designs to be used . Telford had much experience in canal work, and, except for bridge construction, this was the first English road engineering of note. He also worked on the Hollyhead (London–Portsmouth) road offering a London–Ireland connection. Study of that road led to recommendations for maximum gradients of about four percent.

John L. Macadam obtained experience serving on trusts in the 1790s, and interested himself in both technology and administration. He is best known for his technology, primarily the macadam road surface, but he made major contributions to the improvement of trust management.

By the 1820s much of the road system had been improved to macadam or similar standards. There were extensive organized coach service offering 10 mph (16 kph) velocities, mail wagons and mail service, and freight service in two classes, fly wagons or vans for fast freight and slow heavy wagons hauling about 10 tonnes.

**2.3. Tramways**

The technology is old, having evolved first in the metal mines of central Europe and in the copper, lead, and zinc mines of England. There was a natural extension from these beginnings to hauling coal from mines to water. Propulsion was provided in near-level situations by horses. Sharp lifts were accomplished by horses turning capstans, and by steam power when rotary power could be obtained from steam engines (beginning about 1780).

The rail evolved from iron strips fastened to wood through plates and L-shaped plates to forms that begin to look like the T-shaped rail of the twentieth century.

Because the early tramways were associated with mines, they were financed, owned, and operated by mine operators. As demand for coal and canals expanded, tramways expanded. At first this resulted from the new opportunities for mining. Later, tramways were incorporated in canal designs with some serving as feeders where canals could not be practically extended, and some serving as sections of canals, as illustrated by the Pennsylvania portage road and canal which runs east–west across central Pennsylvania.

**2.4. Maritime Transport and Ports**

The tonnages involved in the English open-sea trades had increased very rapidly during the 1700s and also shifted in composition. There were early imports of Baltic grain, flax, hemp, tar, and Portuguese wines with reverse movements of leather, wool, and some minerals, especially copper and tin. Later, the North American fish and cotton trades and the Caribbean sugar trade evolved, with reverse flows of manufactured products. Ship sizes pushed toward 180 tonnes in the North America trades in the late 1700s, while Indiamen (ships traveling between Europe and East India) were even larger.

If port traffic was limited in size, cargo handling was often managed by lightering. A ship would anchor in a bay or river, and lighters (flat-bottomed barges) of near rowboat size would move cargo to and from shore. River barges could be used to reach upriver points. Landing stages accommodated lighters or small barges at the riverside.

Increased movement of goods warranted investment in quays. One reference refers to 1 500 feet (457 m) of quays in London by the year 1700 and remarks on their crowding and needs for additional facilities. Other cases differed depending on trade growth and local circumstances. In Hamburg, for instance, there was early use of warehouses on small, shallow canals. But as ship sizes increased, river anchoring and the use of lighters became common. Eventually, ships anchored to large barges for cargo handling and storage, and lighters worked the barges. That system continued until the 1880s.

The first port investment in Liverpool commenced in 1709 when an enclosed dock was constructed. The enclosed dock was built to deal with relatively high tides, the alternative would have been very deep quays. The facility was built using a small estuarial pool (Liver Pool), and provided 18 feet (5.5 m) of water depth. It cccupied 4 acres (1.6 ha), and could accommodate 100 ships of the size used at that time. Pools or basins began to be constructed in London some years later. The West India Docks opened in London in 1802 enclosed some 30 acres (12 ha).

Companies or local governments provided financing and exerted control, subject to enabling actions by central governments and to customs control and other operational matters of interest to central governments. Navigational aids were generally provided by local organizations. The City of London, for example, provided dredging and channel markings.

The theme in England was quasi-government or private institutions financing, constructing, and operating facilities. That theme continues for air and water ports in many parts of the world.

As ports grew, there was potential for grasping economies of scale. But a factor limiting the capturing of economies of scale was ship size, and ship sizes were not increasing very rapidly. Because of slow cargo handling, the “dead time” in port was long, disadvantaging large, expensive ships. As ships got bigger, the number of sails and crew requirements increased almost linearly, as did the expense and difficulty of construction. (A contemporary rule of thumb called for three crew members per sail on a square-rigged ship.)

For centuries, general cargo ships were measured by register tonnage, with one register ton representing 100 cubic feet (2.83 $m^3$). Net register tonnage is tonnage so measured minus space used for machinery and crew quarters. Large wooden sailing ships in the early 1800s were as large as 600–700 register tons (1700–2000 $m^3$). In Portugal and Spain, one register ton equaled two large kegs. In English ships the measure seems to have evolved from the Baltic trades where one ton of Russian wheat occupied 100 cubic feet. (This discussion will refer to register tons where appropriate. It will not take note of differences between metric and english measurement system tons because they are reasonable approximations for each other for the purposes of this discussion.)

Cargo handling was by hand, with simple mechanical aids. In the 1700s a dock might have a manual capstan used for warping ships, but that's all. Steam engines were available in the 1700s, but were not used on the docks. They were stationary and could not be employed well alongside ships for loading or when handling small quantities. Where the topography was favorable, gravity flow of bulk commodities was used.

There were some manual cranes. A few specialized docks had walking cranes in the period 1750–1850. The crane was powered by laborers walking in a large, say, 16 foot (5 m) drum geared to an external boom and hoist. Powered hoists were not used until the mid-1800s. In this system, central steam engine pumped water to a large storage tower, and the pressure head drove hydraulic crane motors (or water was pumped to an accumulator under pressure).

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**Biographical Sketch**

**William L. Garrison** is Professor Emeritus of Civil and Environmental Engineering and Emeritus Research Engineer in the Institute of Transportation Studies, University of California, Berkeley, His professional concerns and current work focus in the main on technological change in large systems, especially transportation systems.

Born in 1924, Garrison's first instruction in conservation and resource renewal was in 1936. Later he received his bachelor's and master's degrees from Peabody College in Nashville, Tennessee, and in 1950 he received his PhD in geography from Northwestern University in Evanston, Illinois. Garrison served as a meteorologist during World War II. In addition to working in geography and civil engineering, he has been a truck driver, surveyor, and mechanic. He is a seven times father and fourteen times grandfather.

Somewhat of a job hopper, Garrison has held positions at the University of Washington, Northwestern University, University of Pennsylvania, University of Illinois, and University of Pittsburgh, as well as the University of California. During the 1950s he was a Lecturer in the Brookings Institution's Urban Policy Program. Garrison's "Lessons From the Design of a Life," (pp. 99–123 in *Geographical Voices*, Syracuse University Press, 2002, edited by Peter Gould and Forrest R. Pitts) describes these adventures.

In the 1950s and 1960s Garrison served on the Research Advisory Committee and the Advisory Committee on the Highway Cost Allocation Study of the Bureau of Public Roads. Later he served on the National Research Council Research Advisory Committee to the US Department of Transportation; the Independent Study Board of the US Department of Commerce; the Advisory Committee on Small Area Data of the US Bureau of the Census; the Committee on Research of the Economic Development Agency of the US Department of Commerce; the Committee on Economics of the National Science Foundation; the Study Committee on the Social Sciences of the National Science Board; and the Commission on Sociotechnical Systems of the National Research Council. He has also served as consultant to government, nonprofit, and business organizations; the National Transportation Policy Study Commission; and as Chairman of the Transportation Research Board. He has served on the editorial boards of several journals. These and similar activities seem not to have done harm and may have been useful.

Some products from Garrison's recent work include: "Innovation and Transportation's Technologies," published in 2000 in volume 34 of the *Journal of Advanced Transportation* (pp. 31–63); *Tomorrow's Transportation: Changing Cities, Economies, and Lives*, (with Jerry D. Ward; Norwood, Massachusetts: Artech House, 2000, 316 pp.); and "Relations Between Transportation and Production," with Soulerette R.R. (*Transportation Research Record* 1262, 1990). Soon to be published are contributions to the UNESCO *Encyclopedia of Life Support Systems*. Some years ago, Garrison organized the first US conference on Intellignet Vehicle Highway System (IVHS) yielding the report *Technology Options for Highway Transportation Operations*, published University of California Institute for Transportation Studies and California Department of Transportation (UCB-ITS-P-87-1, 1987).