ENGINEERING IN HISTORY

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TWELVE

Modern Transportation

Like the development of electrical communication and power, the emergence of effective transportation during the last half of the nineteenth and first half of the twentieth centuries has been a large factor in the political, economic, and social revolution which has produced our dynamic society. Improved transportation continues to be a factor changing the ways of human life. Cheaper and speedier transportation increases the political unity of a nation, the centralization of political control. It promotes culture by disseminating information, extends great metropolitan areas, facilitates the new organization of industry, effects an ever wider distribution of goods, an increase in wealth, and higher standards of living. Without great transportation and communication systems, the United States would not be the integrated country it is. The National Road described in Chapter 8 was built in recognition of this thesis, to increase the unity and stability of the Union by connecting the East and the West.

The effect of transportation on social conditions is as extensive as its effect on politics. Transportation has exerted a tremendous influence on the spread of populations as well as on the concentration of population in great cities. The shift of population to metropolitan areas since the middle of the nineteenth century is one of the most significant social phenomena; without efficient transportation it would be impossible for huge modern metropolitan areas like London and New York to exist with the present standards of living. Widely available transportation, particularly in the form of the automobile, has changed the whole tempo of our life and has greatly increased the mobility of populations. Transportation has also enormously increased the diffusion of knowledge through

the distribution of printed matter, has made remote centers of education accessible, and has reduced the obstacles to many types of scientific investigations.

The economic effects of improved transportation are perhaps more far-reaching than its social effects. Effective transportation brings to the members of a community many benefits it would be impossible to obtain locally, and it tends to reduce the cost of commodities to the consumer because the cost of transportation of raw materials and finished goods is part of the ultimate cost. Transportation also affects rents and land values; improving transportation can increase land values in one area and cause a decrease in another. In the nineteenth century, for instance, the agricultural land values in the United States increased along the railroads as they spread west. Another example of increased land values is in suburban areas, where the increase was brought about by the private automobile and the public trolley car and bus as well as by railroad service.

There are five major types of transportation: railroad, water, highway, airway, and pipeline, disregarding electric-power transmission which in some instances could be considered an important method of transporting fuel in the form of energy. Table 1 gives the distribution of intercity traffic among these five transport agencies in the United States in 1953.

Table 1 Distribution of Traffic among Transport Agencies in 1953 in the United States

Agency	*Millions of freight ton-miles*	*Per cent*	*Millions of passenger miles*	*Per cent*
Railroads	615,000	52.6	32,450	46.8
Waterways *	185,000	15.8	1,500	2.2
Pipelines	170,000	14.5		
Highways †	200,000	17.1	20,500	29.6
Airways	450	....	14,800	21.4
		100.0		100.0

* Waterways include inland waterways and the Great Lakes.
† Do not include private passenger automobiles.
Source: Data from *Yearbook of Railroad Information,* 1954 ed. Compiled by Eastern Railroad Presidents' Conference.

Within most highly developed countries, railroads transport the largest amount of freight; in 1953 United States railroads carried a total of 2.9 billion tons of freight, whereas the total water-borne commerce, including foreign imports and exports, was 169 million tons. Railroad tonnage was thus more than three times water tonnage.

Railroads

Chapter 9 relates how modern steam railroads began about 1830 in England and the United States and a bit later on the continent of Europe. By 1860 railroads were operating in most of the major territories of the world except Africa, China, and Japan, and by 1883 railroads had appeared even in these areas. In the United States, railroads pushed rapidly westward after the middle of the nineteenth century. The Baltimore and Ohio Railroad reached its western terminus at Wheeling, Virginia, in 1853. The Chicago and Rock Island reached the Mississippi during the year following, but soon aspired to cross into Iowa and even to extend into the rapidly developing prairie territory to the west. Beyond the Great Plains, pioneer engineers were already searching for passes in the almost impenetrable Rockies through which it might be possible to build railroads. It was early realized, and in legislation stipulated by the government in connection with its 1862 land grant to the railroads, that the curves on such a railroad should have radii of at least 400 feet and gradients no steeper than the 2.2 per cent (116 feet to the mile) that had been found feasible on the Baltimore and Ohio. Merely to keep a train moving at a steady or uniform speed on this gradient requires 6½ times the drawbar pull of about 8 pounds per ton that is necessary on straight level track. It was obvious from the first that locomotives of considerably greater power than any previously built would have to be designed, and that in mountainous country where there were heavy grades, even they would often have to be assisted by added power units either ahead of or behind the train.

The first of the thirteen lines in the United States and Canada to cross the Rocky Mountains was the Union Pacific, which met the Central Pacific coming east at Promontory Point, Utah, in 1869, celebrated by the driving of the Golden Spike. These two roads formed a through route from Omaha, Nebraska, on the Missouri River to Pacific tidewater near Sacramento, California. A dozen other mountain lines crossed the Rockies in the period between 1869 and 1914. In general, world construction increased rapidly from 1860 until the first decade of the twentieth century, but before 1915 construction began to slow down, and much track has since been abandoned, especially in the United States. Competition from

other types of transportation has caused this reversal, which has resulted in a net decrease of track mileage after the 1920s. However, there have been important engineering developments since 1860 in all branches of railroad design and construction.

From George Stephenson's 7¼-ton *Rocket* of 1829 to the most recent steam reciprocating-type locomotives of nearly 300 tons there were no revolutionary changes in fundamental design, except for various experimental models which were not commercially successful. The principal development in steam locomotives was a steady increase in efficiency, capacity, and weight on driving wheels. Improvements in efficiency were achieved as in stationary plants by such innovations as superheated steam, mechanical stokers, feedwater heating, etc. The height and width limitations of a locomotive have seriously restricted its efficiency; the maximum efficiencies normally attained in steam locomotives are only about 8 per cent. The efficiency of a thermodynamic cycle is measured by the difference in temperature of the medium employed before and after its use. It is thus desirable to obtain the highest possible initial temperature and the lowest final temperature. Since the condensing of steam is not practicable in a locomotive, the exhaust directly into the atmosphere is at a relatively high temperature, and since boiler pressures and temperatures are necessarily limited, the thermodynamic efficiency is low.

Henry R. Campbell of Philadelphia had invented coupled drivers in 1836. The locomotive *Blackhawk* of that year had a four-wheel leading truck and two pairs of driving wheels, the drivers on each side being coupled to each other by side rods so that they moved together at all times. Locomotives with this wheel arrangement are known as the American type (Figure 12.1). Two years later Joseph Harrison, Jr., connected the two driving-wheel axles on each side with equalizing levers to balance the weight on the axles; he also suspended the weight of the body of the locomotive on three points, the center of the leading truck and the centers of each equalizing lever. This arrangement, which gave stability especially on rough track, has remained fundamental in locomotive design. By 1860 coal was replacing wood as fuel (Figure 12.2), the number of driving wheels had been increased to six in some of the larger locomotives, and the injector for forcing feed water into the boiler had been invented to replace the pumps used up to that time. Henri Giffard, who invented the injector, was also active in building and flying power dirigible balloons.

In designating wheel arrangement of steam locomotives a numerical

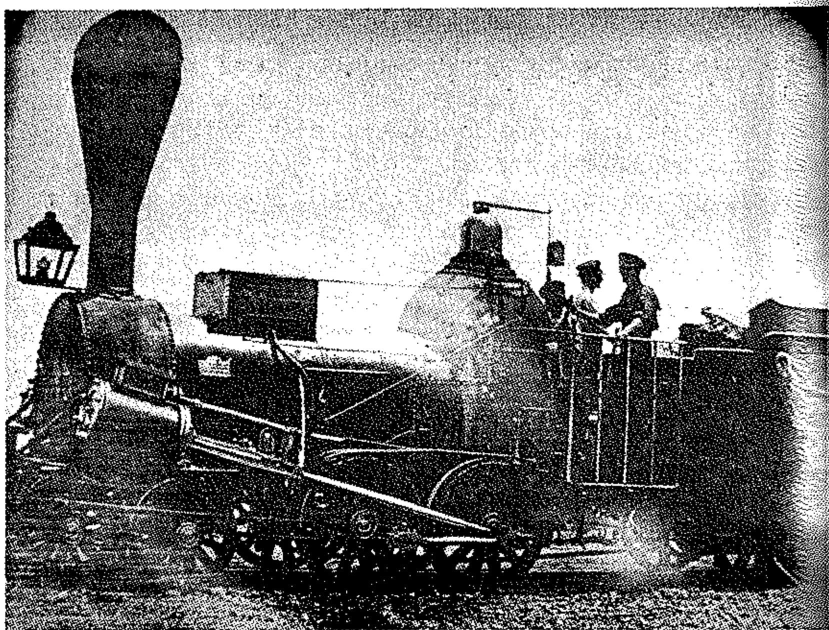

Figure 12.1 Early locomotive of American type, New London and Northern Railroad, 1843 (Courtesy New London Historical Society)

formula has been adopted known as the Whyte system. The first digit in the group indicates the number of leading wheels, the second the number of driving wheels, and the third the number of trailing wheels. If there are two sets of driving wheels on articulated trucks, still another digit is added. Beginning in the 1860s there was a rapid development leading to different types of locomotives. The 2-8-0, known as the Consolidation, with eight driving wheels, was introduced during this decade. Engines of the 2-10-0 type were also built at this time, but the 2-8-0 was the most popular heavy American locomotive until the end of the century. The 1860s also saw the introduction of steel into locomotive construction, and in the 1890s the wider, longer, and more efficient firebox burning low-grade coal came into general use. The larger firebox necessitated the introduction of trailing wheels of small diameter which could be placed under the firebox so that it could be built out over the wheels to the full width of the locomotive rather than confined in the space between the wheels.

Campbell's coupled drivers and many other improvements were originally made in the United States, where demands for increased power

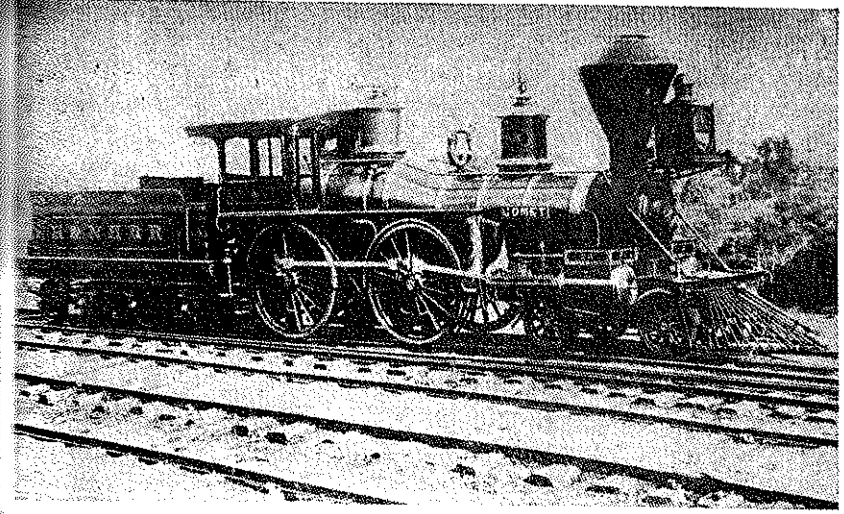

Figure 12.2 Coal-burning passenger locomotive, 1864

were greater than in most other parts of the world. In 1876, however, Jules-Theodore-Anatole Mallet (1837–1919), originally of Switzerland, invented the compound locomotive which made the steam work twice, as had already been done in stationary and marine engines. Mallet led the steam first into a high-pressure cylinder, from which it passed after partial expansion into a larger low-pressure cylinder, after which it was exhausted to the air. Although the principle of compounding was first used in the United States in 1889, it was never widely used.

By the beginning of the twentieth century there were three principal types of steam locomotives: the switcher or shunting locomotive, the passenger road locomotive, and the heavy-duty freight road locomotive. In 1900 designers in the United States were concentrating on freight-service engines with high tractive effort rather than high speed, and on high-speed passenger locomotives for relatively light trains. The maximum efficiency obtainable from these locomotives under favorable conditions was on the order of only about 3 per cent, and there was a general realization that efficiency and power output would have to be increased to meet the heavy traffic demands and competition from electric locomotives. It had been an accepted philosophy that the steam locomotive should be as rugged and simple as possible because of the exacting demands of road service and that refinements were of secondary importance.

In 1900, Wilhelm Schmidt of Germany had invented a device for

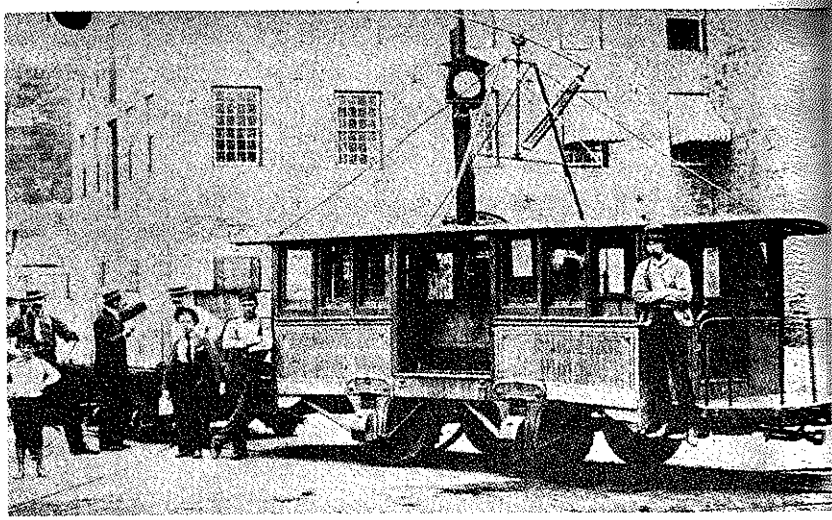

Figure 12.3 First American electric freight locomotive, Ansonia, Connecticut (Courtesy Charles Rufus Harte)

superheating steam, which was of increasing importance in stationary power production. Schmidt led the "saturated" steam through small tubes inserted inside the boiler flues and thus converted the saturated steam into superheated steam. Maximum steam pressure on locomotives in 1900 was approximately 200 pounds. During the twentieth century these pressures have been increased, but they are even now not generally higher than 250 pounds and seldom as high as 300 pounds. These pressures are much lower than those in stationary power plants and are necessarily fixed by the limitations of the locomotive boiler. The temperature of saturated steam is increased as the pressure rises; increased pressures thus mean higher steam temperatures, and superheating raises temperature still more. The major limitation to the power output of coal-burning locomotives with firing by hand is the amount of coal the fireman can shovel. The constant opening of the firebox door necessary in hand firing means the admitting of streams of cold air and a serious reduction in efficiency. Mechanical stoking and oil firing have removed this limitation and have quadrupled the horsepower production of locomotives. Other detailed improvements in the working parts of steam locomotives have combined to double their efficiency in the twentieth century, but a maximum of 8 per cent even under favorable conditions is still very low compared to that of the steam turbine of the stationary plant or to the internal-combustion engine. One of the first successful oil-fired locomotives was the

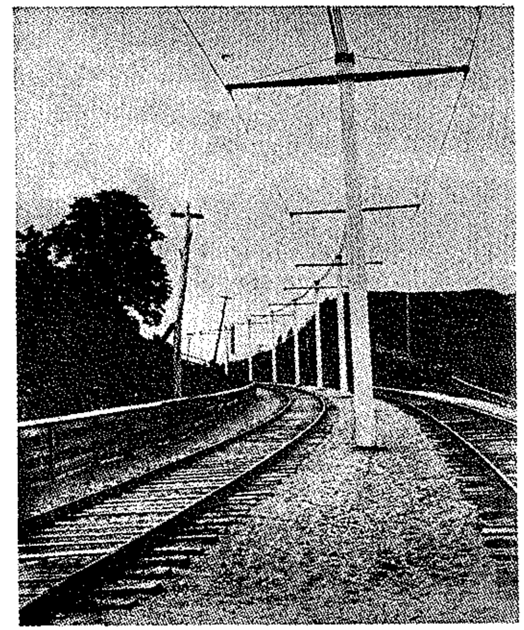

Figure 12.4
First electrification of a steam railroad in the United States, 1895

Petrolea, built for England's Great Eastern Railway in 1886. By 1900 several American roads were using oil as fuel, but there were never more than 15 per cent of United States steam locomotives fired with oil.

Electric street railways had begun commercial service in the 1880s and developed very rapidly during the next quarter century. The first American electric freight locomotive had operated on the tracks of the Ansonia, Derby and Birmingham (Connecticut) street railway in 1888 in competition with a steam railroad (Figure 12.3). It was not unnatural that electric power should be called upon to help solve the problem of steam railroads. In 1895 the New York, New Haven and Hartford Railroad applied electric power to the operation of its Nantasket Beach branch near Boston (Figure 12.4), the first electric operation of a steam railroad in the United States. Later the same year the Baltimore and Ohio Railroad completed the first main-line railroad electrification in its mile-and-a-half-long tunnel at Baltimore (Figure 12.5) to eliminate offensive smoke and heat conditions. Other electrifications in the United States came during the following decade. The early discussions among engineers as to the relative merits of alternating or direct current for locomotives and railroad motor cars were very bitter, just as some years earlier had been the discussion as to the better method of electric-power distribution for commercial

Figure 12.5 Electric locomotive pulling Baltimore and Ohio train, 1895 (Courtesy General Electric Co.)

and domestic service in cities. The alternating-current distribution adopted in the United States for traction was nominally 11,000 volts, 25 cycles per second, and direct current usually at nominally 600, 1,500, or 3,000 volts. In Europe the alternating-current distribution is usually at 15,000 volts with frequencies either 15 or 16⅔ cycles per second, and direct current usually at 600 or 1,200 volts. If the distribution voltage is more than 600 volts it is necessary to install overhead wires, otherwise third rail is usually employed.

In the United States, only 2 per cent of the total main-line mileage is electrified, but abroad where fuel is scarce, and especially in sections where water power is plentiful, railroad electrification has developed more extensively. While electrification of railroads in the United States has not been as general as abroad, the world's largest steam-railroad electrification, completed in 1935, is that of the Pennsylvania Railroad (Figure 12.6) on its lines connecting New York with Philadelphia, Washington, D.C., and Harrisburg, Pennsylvania. The electrified track totals 2,228 miles and covers 664 miles of road. Very heavy passenger and freight service is handled in this system. Because the power is supplied from the outside, the electric locomotive produces a high output, particularly as compared with the steam locomotive. Furthermore, electric locomotives may be used in sets of two or more units controlled by one driver.

The diesel-electric locomotive began to replace the steam locomotive for main-line operation in the United States during the 1940s, and no main-line steam locomotives have been built by locomotive companies for domestic use since 1949 (Figure 12.7). Railroads and terminal companies

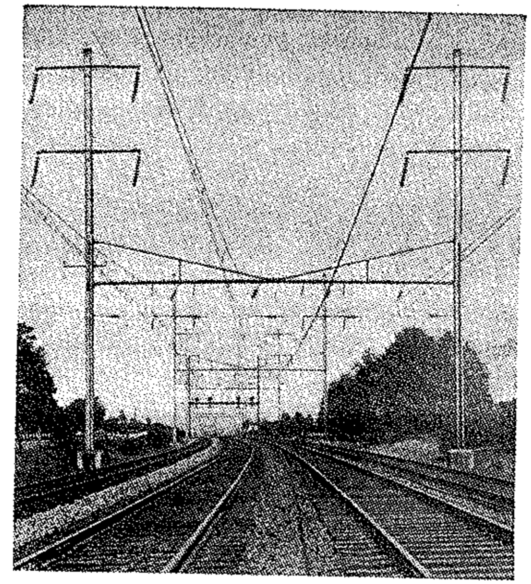

Figure 12.6 Pennsylvania Railroad catenary construction, 1935 (Courtesy Pennsylvania Railroad)

had been using diesel-electric switchers since 1924, but it was not until the late 1930s that orders for diesel electrics began to mount at an increasing rate. The principal components in the diesel-electric locomotive are the diesel engine, the electric generator, and the traction motors. Rudolph Diesel (1858–1913) obtained the basic patents for his engine in Germany in 1892. He first obtained power from one of his engines in 1894, and a later model tested under load early in 1897 showed an efficiency which exceeded that of any other thermal prime mover of the period. Five years later several hundred diesel engines were in operation in stationary power plants. Diesel designed his engine on the general pattern of the gas engine perfected by the German inventor Nikolaus A. Otto (1832–1891) in 1876. The essential features of Diesel's engine are the cylinder equipped with a piston and a fuel-injector nozzle in the cylinder head. When the piston moves downward on the suction stroke, it draws in air. The suction was originally directly from the atmosphere, but nowadays the engine is usually supercharged by air forced into the cylinder under pressure. The return stroke compresses the air imprisoned in the cylinder to a very high pressure and raises its temperature to a point above the flash point of the fuel. When the piston reaches the end of the compression stroke, the fuel injector sprays fuel oil into the cylinder. The hot air ignites the oil, which burns and forces the piston down. In the gasoline engine the explosion of the gasoline-air mixture is obtained

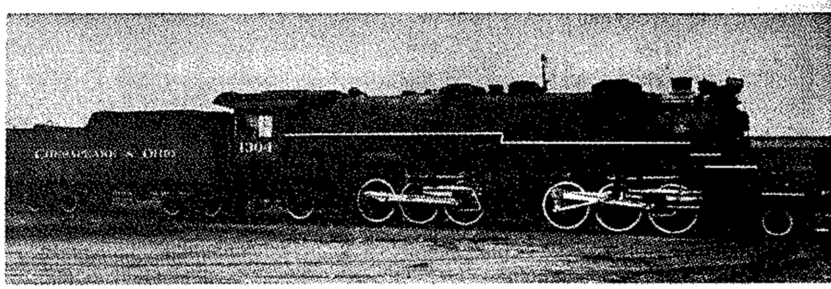

Figure 12.7 Last main-line steam locomotive built by the Baldwin Locomotive Works for use in the United States (Courtesy Chesapeake and Ohio Railway)

by an electric spark, whereas electric ignition is not necessary in the diesel engine. The return stroke expels the products of combustion into the air, and the cycle repeats. This sequence is known as a four-stroke-cycle diesel, but there are many two-stroke-cycle engines where the combustion takes place every other stroke and the exhaust of burned gases and inlet of fresh air takes place simultaneously at the end of the power stroke. Locomotive engines are of either type.

Like the automobile engine, the diesel-locomotive engine requires some type of variable drive mechanism between it and the driving wheels to take care of varying speed and power demands in starting and in climbing hills, while the engine itself works at generally constant speed. Neither the mechanical gear nor the fluid transmission, such as are used in automobiles, is adequate for the high power required in a locomotive. The variable drive in the diesel-electric locomotive (Figure 12.8) is obtained by a direct-current electric generator on the engine shaft which supplies the series-wound, direct-current traction motors with electric power at varying voltages obtained by control of the generator field current. The function of traction motors can be electrically reversed to generate power on downgrades, and this power is absorbed by heating grid resistance. This arrangement acts as a brake on the train going downgrade, since the mechanical energy of the train is changed to heat. This dynamic braking, as it is called, saves wear and tear on the brake shoes and wheels.

American railroads put the first high-speed passenger-service diesel-electric locomotives into operation about 1935. Freight-service diesels appeared in 1938, and the dual-purpose road-switcher type came into use in 1940. The initial cost of a diesel-electric locomotive is relatively high as compared with a steam locomotive of equal nominal horsepower.

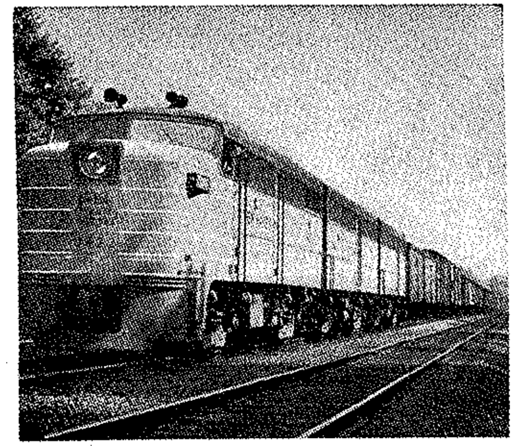

Figure 12.8
Diesel-electric locomotive (Courtesy New York, New Haven and Hartford Railroad)

However, the diesel locomotive has important advantages. The useful power of a diesel locomotive may be greater than that of a steam locomotive of the same nominal rated capacity because the diesel power is available over a wider range of speeds. The engine terminal expenses are generally less with the diesel locomotive because there is less work to be done by the hostlers at the terminal. There are no boiler feedwater complications, which are troublesome in some parts of the world where steam locomotives are used. The diesel fuel, a relatively high-grade oil, is expensive but easy to handle and store at the terminals. The diesel electric has an efficiency of about 30 per cent, which is four or five times that of the steam locomotive. Moreover, it can be assembled in multiple units under the control of one crew, and these multiple units may produce tractive effort and power concentrations far greater than a steam locomotive. There is no doubt that one of the most important railroad-engineering developments of the twentieth century is the diesel-electric locomotive.

The railroad car has two principal functions: it must carry a load and it must operate as a link in a chain, or train, of cars. Freight-car bodies have become diversified for dozens of types of shipments—livestock, oil, cement, coal, refrigerated products are but a few. The running gear, couplers, air brakes, and other appurtenances have, at least on the North American continent, become standardized to permit interchangeability on all standard-gauge railroads.

George Stephenson, who later built the locomotive *Rocket* described in Chapter 9, constructed the first railway passenger coach in the world. In the early 1830s most of the "carriages" were either converted four-

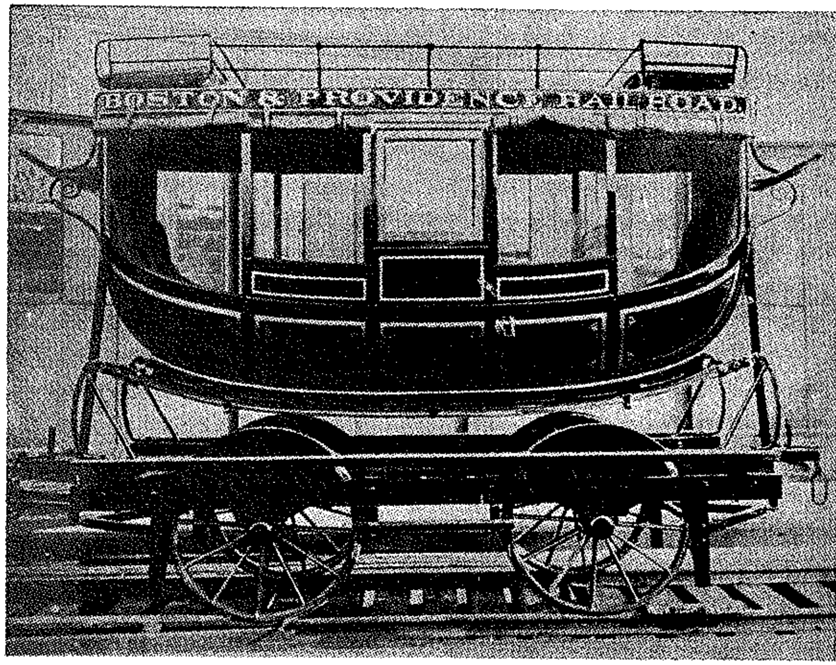

Figure 12.9 Early American railroad passenger coach, 1834 (Courtesy New York, New Haven and Hartford Railroad)

wheel open "waggons" with benches or converted stagecoaches (Figure 12.9). The early freight cars in England were all converted wagons, or lorries, which could carry a load about twice their own weight. These early cars had chains for couplers and were provided with hand-operated brakes only. Since there were no buffers between the cars, there was considerable slack in a train, and whenever the engineer applied the brakes on his locomotive, each car ran in on the car ahead and the whole train ran into the engine. When the engineer started the locomotive and took up the slack in the coupling chains, there was another series of jolts which, as one observer wrote, would "jerk the passengers out from under their hats." In 1831 Ross Winans built horse-drawn, enclosed passenger cars for the Baltimore and Ohio. These cars had seats for 20 passengers and were equipped with two four-wheel bogie trucks and brass bearing boxes similar to those still used on many cars. Although the bogie, or truck, had been patented in England in 1812, British cars did not use them until about 1880. The American railroads began to use Winans's design in the 1830s and soon had cars 40 feet long on two four-wheel trucks.

Both passenger- and freight-car bodies were wood and iron, with wood the predominant material.

Passenger cars in Europe, having developed from the idea of a combination of stagecoaches, were divided into separate compartments. American passenger cars were from the early days much longer than British and Continental cars and because of climate conditions were not divided into compartments. They had from the beginning the typically American center aisle, springs for smooth riding, stoves for heating, candles or oil lamps, and later, water coolers and toilets. They had no vestibules but instead open platforms to permit passengers to pass from one car to another, whereas there was no passageway between European cars for many years.

During the first four decades of railroad development many hundreds of devices for stopping railroad cars were devised and patented. Only a few of them were found to be practically useful. Of these the most common was the hand-operated type which the brakeman set by twisting a horizontal handwheel set on a vertical post at one end of each car. Railways still use hand brakes for the control of detached cars. As train lengths, speeds, and unit loads increased, it became obvious that the engineer should be able directly to control the braking for the entire length of a train. In the late 1860s the successful use of compressed air for drilling the Mont Cenis Tunnel impressed young George Westinghouse (1846–1914) with the possibility of using compressed air to operate brakes. His first patent, covering the straight-air type of brake, was issued in 1869 when he was only twenty-three. In the locomotive cab there was a main compressed-air reservoir from which a hose or pipe, the train line, extended underneath each car, the entire length of the train. This hose connected with a brake cylinder under each car. When the engineer wished to apply the brakes he opened his valve and the compressed air brought each brake cylinder into action almost—but not quite—instantaneously. These air brakes slowed the train or brought it to a sometimes violent stop unless a leak developed in the hose, impairing the brake power, or the train broke in two, in which case the cars had no brakes at all except the old hand brakes.

Westinghouse recorded in his 1910 presidential address to the American Society of Mechanical Engineers, entitled *The Conception, Introduction and Development of the Air Brakes,* the first test of his new brake: "The Superintendent of what was then known as the Panhandle Railroad, Mr. W. W Card, offered to put the Steubenville accommodation train at my disposal to enable me to make a practical demonstration. The apparatus exhibited was removed from the shop and applied to this train which consisted of a locomotive and four cars. Upon its first run after the apparatus was attached to the train, the engineer, Daniel Tate, on emerging from the tunnel near the Union Station in Pittsburgh, saw a horse and wagon standing upon the tracks. The instantaneous application of the air brakes prevented what might have been a serious accident, and the value of this invention was thus quickly proven and the air brake started upon a most useful and successful career."

In 1872 Westinghouse's second invention, the plain automatic brake, made slowing and stopping simpler, smoother, and more certain. This type was developed from the original straight air brake by adding under each car an auxiliary reservoir with a triple valve which together with the train line is normally kept filled with compressed air at about 75 pounds pressure. When pressure in the train line is reduced or cut off normally by the engineer, the pressure from the auxiliary reservoir under each car, acting through the triple valve on its own brake cylinder, partially or completely sets the brakes. In case the train line is ruptured, all the brakes are automatically set by the pressure of the air in the individual reservoirs. The triple valves are essential features of the automatic air brake. The improvements in air brakes since 1872 have been mainly in details. American manufacturers and railroad men have conducted many series of extensive tests of every feature of brake equipment and of various brake types, beginning with the Burlington tests carried out with freight trains on the Chicago, Burlington and Quincy Railroad in 1886–1887.

In England the first formal series of brake tests was made on the Midland in 1875. The vacuum automatic brake, first used on the Great Western Railway in 1876, was widely adopted after the tests. In England, railway equipment is lighter in weight than in the United States. In 1923 the vacuum brake became standard equipment on English roads; however, the air brake is standard on the Continent. United States railroads have recently developed a brake known as the AB brake that controls freight trains of any length traveling sometimes faster than 70 miles an hour, while new types of brake shoes on passenger cars take care of trains traveling faster than 100 miles an hour. The importance of effective brakes is evident when one realizes that the energy in a moving train is proportional to the square of its speed. For example, a train moving at 80 miles an hour has nearly twice the energy of a train of the same

weight moving at 60 miles an hour, and a train at 100 miles an hour has nearly three times the energy. This must be absorbed to stop it. The air brake is more than a mere safety device; it gives the engineer control over the speed of his train at all times and has added to railroad traffic capacity, allowing longer, faster, and more frequent trains. Were Mrs. Carlyle able to ride in a streamliner of the 1950s she would not have to worry as she did in 1836 about "the impossibility of getting the horrid thing stopt."

The lot of a brakeman on early American railroads was not a happy one, especially before the advent of the air brake when he might have to run along freight-car roofs to tighten up many hand brakes whenever a stop was indicated. Another dangerous operation was the coupling of cars in the days when the only device used was the link-and-pin coupler. This procedure required a man to stand between the stationary car and the one approaching it in order to drop the heavy coupling pin into the double link at the proper instant. The first automatic or knuckle coupler which closed and locked on impact was invented in 1873 by Eli Hamilton Janney, a Virginia farmer.

The early American passenger cars were lighted by tiny, dim, and smelly lamps, most of which burned whale oil, later kerosene. Pintsch gas or acetylene gas lamps gradually replaced oil lamps on most roads and were standard equipment for years. Pintsch gas, rich in illuminating power, was made from petroleum; the gas was compressed into portable tanks placed under each car. The first electric lights were installed in a Pullman car in England in 1881, using power supplied by crude storage batteries. In the late 1880s an effective electric-lighting system, the power for which was supplied by a generator, began to replace gas. The first train in the United States to be lit by electric lights was the Atlantic Coast Line's *Florida Special* in 1887. Here the current was supplied from a single generator operated by steam at the head end of the train. This arrangement was not satisfactory for a number of reasons and was therefore supplanted by installing under each car a generator connected by a belt to the car axle and so designed that it could furnish power regardless of which direction the car was moving. This type of lighting system now also supplies power for air conditioning and other demands; in many cases as much as 50 horsepower may be required for each car, or 500 horsepower for a 10-car train. Rugged storage battery units with ample capacity furnish light and power while cars are not in motion.

The Pullman Companv in 1907 built the first all-steel car, which was perhaps the greatest single advance ever made in railroad-car construction. Steel cars are obviously much safer than wooden cars. All American passenger cars and most freight cars built in the last thirty years have been of steel or aluminum alloys. The first all-steel cars on the European continent were introduced in 1922, but many European roads still use wood. Air conditioning, or cooling and drying air in summer, was first tried by the Baltimore and Ohio in the form of an ice-cooled car in 1884, but mechanical air conditioning was not generally introduced on American railroads until the 1930s. Roller bearings first replaced Winans's brass friction bearings in the late 1920s; the roller bearing reduces drag, especially in starting. The lightweight aluminum and steel-alloy streamliners and lightweight freight cars appeared in the 1930s. Some of the new freight cars can carry loads four times their own weight.

In the United States the majority of signals are now electrically operated, and most control of trains involves the use of the telephone, which has generally replaced the telegraph. The evolution of electric signaling and control depended directly on the inventions described in Chapter 11. Until the 1920s signals had the one function of preventing accidents; since that time they have also been used to communicate orders to the engineer. Control now means largely the dispatching and routing of trains, and efficient control systems permit a high train density on any line. Over five hundred trains travel each day over the four-track line leading into the Grand Central Terminal in New York, and during morning and evening peak hours there is especially close spacing of trains. Without an efficient method to control this heavy traffic there would be chaos.

One of the first railroad signals was a basket covered with a white cloth which could be raised to the top of a tall pole. The New Castle and Frenchtown Railroad, now part of the Pennsylvania, used this signal in 1832; it was probably adapted from a type of signaling post used during the American Revolution to send coded messages. When the basket of the New Castle and Frenchtown signal was at the top of the pole it meant "clear"; when at the bottom, it meant "stop." A failure of the mechanism would drop the basket to the stop position so that a "false clear" was avoided—a cardinal principle in all signal construction. In later years, even after the telegraph was used for train control, large hollow balls were substituted for the baskets, and the "clear" signal was the origin of the railroad term "highball," meaning go ahead. All early signaling and control worked on a time basis. At perhaps twenty minutes after a train had left a station the signal would be changed from "stop" to "clear"; the

assumption was that a following train would not overtake the first if the latter had a twenty-minute start. However, anything from a mechanical failure to livestock on the track could detain the first train, allowing the second to overtake and perhaps collide with it.

The Yarmouth and Norwich Railway in England first used the telegraph for traffic control in 1844, and the Great Western Railway installed a manually operated telegraph signal at its 2-mile Box Hill Tunnel in 1847. American railroads were slow to use the telegraph, and when Charles Minot (1810–1866), superintendent of the New York and Erie Railroad, first proposed about 1849 the construction of a telegraph line to be used to control traffic, he had great difficulty in obtaining approval from the directors. American railroad men had at first little enthusiasm for the telegraph. An English visitor writing in the *London Quarterly Review* of June, 1854, commented on its rarity along railroad rights of way, adding that as a consequence "locomotion in the United States is vastly more dangerous than in England."

Interlocking connects the signal to the track switch so that the signal cannot be set for a train to proceed unless the switch is in the proper position. In the 1850s the British invented interlocking machines which would prevent an operator in a control tower from throwing a switch without properly setting the signal. The first railroad to use interlocking was the London, Chatham and Dover Railway in 1856. Prior to that time a signalman moved a switch and changed a signal by hand independently, a procedure under which human errors were frequent and often disastrous. The Pennsylvania Railroad had installed the first manually operated block signaling system in 1864. The principle of this system was based on the subdivision of the railroad for traffic-control purposes into lengths of tracks called blocks, each of which might be a mile or several miles long. At each end of the block were operator-controlled signals to govern trains approaching from either direction on the single track. When a train entered a clear block the signalman set his signal to stop any following train and telegraphed the operator at the other end of the block who set his signal to prevent any train traveling in the opposite direction from entering the block. The first signalman also notified the operator at the other end of the block from which the train had proceeded, and he changed his signal to "clear." Subsequently a locking device was added to the signals so that the operator could not change the signal from "stop" to "proceed" unless the signalman at the other end of the block unlocked it for him. There are still some manually operated block signals in the United States, but the block signals on heavily used lines are now generally automatic. The Southern Railway in England had tried out an automatic electric signal as early as 1844, but it was not effective. William Robinson developed the first successful track circuit for automatic signals in the United States in 1871. In the automatic signal system an electric current passes through one of the rails of the block from a source of supply at the leaving end of the block and through an electric relay at the opposite end and thence returns through the other track rail. As long as the current flows normally, the relay is energized and keeps the signal at "clear." As soon as a train enters the block the current is short-circuited through the axles of the train and does not pass through the relay which immediately changes the signal to "stop." The relay gives the "stop" signal also in the case of a broken rail which interrupts the rail current. This automatic scheme has made unnecessary manual signal operation at the ends of the blocks.

A train-control system is designed to set the train brakes or give an audible signal in the locomotive cab of a train which passes a signal set against it. Mechanical trip devices to set the brakes had been patented as early as 1880. Two general types of electric train control have been installed on railroads in the United States. These are known as intermittent and continuous devices. In the intermittent arrangement an electromagnet is installed near the running rail at each signal location, and other magnets are mounted on the trucks of the locomotive. If a signal is set at a restrictive position, the track magnet is energized, and if the locomotive engineer does not recognize and manually acknowledge or forestall the indication by operating a switch before the locomotive magnet enters the field of the stationary magnet, the air brakes are automatically applied. Since there is no device connected with this system between signal locations, the control is effective only at the wayside signals and the scheme is therefore intermittent.

What is known as a coded continuous-induction control system, now the most generally used or American method, was first installed in 1927 after much cooperative experimentation. In this system the locomotive truck frame carries an induction coil near the rail ahead of the leading axles. A current is induced in these coils from the magnetic field which surrounds the track rails in which the signal current flows, and vacuum tubes on the moving equipment amplify the induced current and show signals in the cab. The circuit flowing in the track rails is controlled by the coder, consisting of a small motor operating electric switches which

interrupt the rail current 80, 120, or 180 times per minute, depending on the position of the signals serving the block or section of track. If the block is occupied, the motor stops and there is no code impressed on the track circuit; the cab signal thus indicates "stop" and the situation must be acknowledged by the engineer. If the block is clear but the next block is occupied, this coder gives 80 interruptions per minute and the cab signals indicate this situation. If two blocks ahead are unoccupied, the code is 120 times per minute, and if three blocks are clear, the 180 interruptions per minute are so indicated in the cab.

Some railroads have installed what is known as centralized traffic control, or C.T.C., on sections of their lines in order to eliminate local signal towers along the route. This system, first employed in the United States in 1925, enables an operator located at a convenient place to control interlocking signals and switches over a large railroad territory. As the trains move over this territory their position is shown automatically on an electrically illuminated track plan so that the operator knows at all times just where each train is. On his desk are small knobs to control signals, and small levers to control switches, perhaps more than 100 miles away. Visible indicators show the position of each switch and signal. The operator may plan just what he wishes each train to do at any time and operate the appropriate track switches and signals to indicate his plan to the locomotive engineer. There are thus no train orders and no operators at any other point. The whole system is handled on a pair or two of wires strung along the right of way without interfering with the automatic block signals which continue to give their own indication of track conditions in the block. It is one of many devices adopted by railroads in the interest of economy that not only save labor costs but also increase traffic volume.

Street Railways

The electric street railway has had a brief but hectic history in the United States. From the late 1880s to 1950 it furnished an enormous amount of urban transportation before being largely displaced by a motorized version of one of its predecessors, the omnibus, which dates back to the seventeenth-century philosopher Blaise Pascal. The first horse-drawn coaches, or omnibuses, began public service on regular schedules in Paris in 1662. They were reasonably satisfactory from an engineering point of view, but once the novelty had worn off their popularity declined and the company failed. The first commercially successful serv-