EFFICIENT RAILWAY OPERATION

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EFFICIENT RAILWAY OPERATION

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PREFACE

After many years of experience in railway construction, operation and administration, the author has published a series of works on those subjects, principally in relation to the successive stages of regulation of the railway system of the United States by means of legislation, both State and national. These works are largely the outcome of the author's own personal knowledge, experience and research, and reference is herein made to them, in some cases, where the same matters have been discussed at greater length in the former volumes.

It is the aim of the present work to describe the progressive development of efficiency in the operation of the railway system of the United States, as compared with similar progress in other countries. It has been prepared at the suggestion of many persons who have inquired for authoritative works on the subject, that would be of value especially to students in technical schools and to junior railroad employees, as well as of interest to the general reader. With this two-fold object in view, there have been added, in appendices, very complete tables of statistics and much strictly technical information, drawn from official sources. Reference to authorities and explanations of terms have been given in footnotes.

The work is devoted to operation, as distinguished from administration. It deals with facts, and not with opinions; therefore, it does not discuss matters of finance, or rates or labor questions.

The author desires to acknowledge the valued assistance of railroad officials and friends in bringing the information down to the present year, and for much that is included in the chapter on the use of railroads in war-time. In the revision of technical matter, preparation of index and addenda, correction of proofs and general supervision of the work through the press, he has had the aid of Charles A. Hammond, C. E.

Gwysaney, Lenox, Massachusetts,
June, 1918

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EFFICIENT RAILWAY OPERATION

CHAPTER I

EVOLUTION OF THE RAILWAY

Primitive Ways of Communication by Land

The essential feature of commerce is the distribution of commodities among persons and places, between producers and consumers. In a small way, this purpose may be effected from hand to hand between the persons themselves in the same community. But the community itself does not exist in isolation. The needs and desires of its members extend to commodities that it does not produce, which, therefore, must be obtained elsewhere. Before the introduction of the precious metals as a medium of exchange, the demand for such commodities was supplied by barter between communities of the articles that were not produced in both. Specialized groups fulfilled this function and thus transportation became a prime factor of commerce.

The prosperity of an industrial community depended upon its production in abundance of commodities desired by other communities with which it was in communication. The lack of ways of communication restricted its field of commercial activity. As these were extended, its social efficiency improved, and the opportunity was afforded for a corresponding increase in the economic efficiency of each of its members. The means of transportation depended upon the character of the ways of communication. When these were but steep and rugged footpaths, transportation was effected by gangs of porters. Over the sandy deserts, the burden was borne by asses, until camels were domesticated and trained as pack-animals. On navigable streams, commerce was freighted on rafts or boats propelled by poles or oars until the narrow seas were reached and large craft could be wafted on by sails to their destinations.

Transportation was for ages effected by the expenditure of vital energy. Whether the human being bore a burden on head or shoulders or on a hand-barrow, the energy thus expended was purely vital. The mechanical powers were applied to industrial processes for an indefinite period before they were applied to relieving the bearers of their burdens or to reinforcing their muscular strength by artificial means. It was not until the end of the Middle Ages that the first step in this direction was taken through the invention of the wheelbarrow by that universal genius, Leonardo da Vinci. When this means of transportation was developed in the hand-truck and hand-cart, its highest standard of efficiency had been attained, until the invention of the bicycle. As it was with human carriers, so it was with beasts of burden. Both of them, in long processions, slowly trudged over sandy deserts and mountain passes, stumbled in fords and struggled through mire, which no vehicle heavier than the war-chariot could traverse.

It was under these conditions that transportation was conducted, until the roads that radiated from Rome were paved to facilitate military operations. During the dismemberment of the Roman Empire, these long-neglected highways became disintegrated, and the Middle Ages relapsed into the primitive methods of transport by men and beasts. For twelve hundred years after the Romans had withdrawn from Britannia, road-repairs in England were left to the perfunctory efforts of parochial authorities, aided by voluntary contributions from religious bodies or from neighborhood land-owners. In 1554, the maintenance of the public highways by compulsory labor was definitely placed upon the parishes by Act of Parliament, supplemented in 1663 by authority to substitute a road-tax for compulsory labor. As internal commerce increased, this burden of taxation was shifted to the users of the principal thoroughfares by the establishment of turnpike-gates for the collection of tolls, though the parochial system of road-repairs was not generally abolished until 1835.

The condition of the highways under this system is almost inconceivable at the present time. The saddle-horse and the pack-horse were the principal means of conveyance. In 1672, the total number of passengers by "stage-wagons" over the three routes from London to York, Chester and Exeter amounted to 1872. As late as 1753, four days were required to go by post from London to Liverpool, about 210 miles, and in 1760 the Edinburgh coach for London made but one trip a month, being from fourteen to sixteen days on the way, a distance of some 400 miles. In 1776, it took six weeks for an eight-horse wagon to make the round trip between London and Edinburgh with four tons of goods. By 1784, "flying machines on steel springs" had come into general use with improvement in the condition of the highways. The journey from London to Bath, 107 miles, was made between 4.00 A.M. and 11.00 P.M., and to Dover, 77 miles, from 4.00 A.M. to the evening of the same day. In that year "mail coaches" were put on the route between London and Bristol, accomplishing the distance of about 120 miles in sixteen hours. By 1830, the mail was carried from London to Liverpool in 30 to 36 hours, according to the condition of the roads.

Meanwhile, internal communication had been facilitated by the gradual introduction of more efficient methods of road construction and repair under the turnpike-system. This plan of maintaining the highways by collection of tolls met at first with great opposition. Turnpike-gates were frequently destroyed by rioters who, in some instances, were only dispersed with bloodshed. But, between 1760 and 1774, the principal highways in England were controlled by turnpike-trusts.[1] Their subsequent transformation was accomplished by Telford and Macadam between 1803 and 1836. From that time forward, the roads in England were the models for the Continental road-makers. Wherever these examples were imitated, the transport of men and things by land was brought to a state of efficiency in which the strength and endurance of draught-animals were economically applied, and the energy of man was concentrated upon managing and caring for them. Beyond this point, further progress in efficiency of transportation was unattainable by the utilization of vital energy alone.

Development of Water Ways

The opportunities for relieving the strain upon man and beast afforded by water-transportation had long been availed of in the internal commerce of England. The principal rivers were utilized to points far inland by the lightest types of barges, and the ports at which their lading was transferred to sea-going craft became important commercial centers. But the maintenance of a navigable stream is a continuous contest with the never-ceasing forces of Nature — with the effects of currents, tides and floods in wasting away their banks, in obstructing their channels with shoals, and in diverting their courses; while the depth of water varies with the seasons.

The continual deterioration in the navigable water-courses, that gradually affected their value as arteries of commerce, it was sought to overcome, in the usual English fashion, by leaving the remedies to be applied by the enterprise of the communities or individuals more directly affected thereby. As early as 1424, Parliament empowered a commission to provide for the removal of shoals in the river Lea by the collection of tolls. This river was then navigable to Ware, some twenty-five miles from its confluence with the Thames, below London. In 1571, the Corporation of the City of London was authorized further to improve the navigation of this river by straightening its channel. The principal inducement to river-improvement was the importance of supplying the metropolis with coal. For this purpose, projects of greater magnitude were undertaken in connection with the navigable streams in the basins of the Severn, the Wash and the Humber. Liverpool emerged from obscurity in 1694, as a consequence of the improvement of the Mersey, to facilitate the export trade of Manchester and of Chester.

The difficulties attendant upon the permanent removal of shoals, led to the construction of locks at such points, and to a manifestation of the

[1] For further information as to the development of internal communication in Great Britain, see "History of Inland Transport and Communication in England," Edwin A. Pratt. Kegan Paul, Trench, Trubner & Co., London, 1912.

advantages of slack-water navigation, by which the resistance of currents and tides, the silting up of the channels and the wastage of the banks were obviated. The progressive minds among those interested in internal navigation were accordingly turned to the development of communication by canals. A canal-system not only obviates the disadvantages in river-navigation just cited; it has also the merit of affording more direct communication with centers of production inaccessible by natural water-courses. This is peculiarly the case as to quarries and mines. In 1720, an attempt to make the Sankey Brook navigable for coal-traffic to Liverpool was abandoned in favor of a parallel canal. But attention was more generally directed to this mode of transportation by the completion of the canal connecting Manchester with Liverpool, constructed by James Brindley for the Duke of Bridgewater and opened for navigation in 1773.

Water-communication across Midland England was secured four years later by a canal connecting the waters of the Mersey and the Trent, which overcame an elevation of 316 feet by a flight of 35 locks and a summit-tunnel, a mile and two-thirds in length; and the Huddersfield Canal, carried over the Yorkshire Hills at an elevation of 436 feet through a three-mile tunnel. The Mersey and the Severn were connected by the Grand Trunk Canal; the Grand Junction Canal joined the Thames with the Mersey and the Trent, and this chain of internal navigation was completed by the construction of the Thames and Severn Canal. From 1758 to 1803, there were passed 105 Acts of Parliament authorizing the construction of canals, to a total length of 2896 miles.

A great impetus was given to the industries of Great Britain by this system of internal navigation, which was further stimulated by the contemporary development of the steam-engine by James Watt. From 1700 to 1795, the output of coal in the United Kingdom increased from 2,600,000 tons to 10,000,000 tons. From 1740 to 1796, the iron production increased from 17,350 tons to 124,879 tons, and from 1720 to 1800, the imports of raw cotton increased from 2,000,000 pounds to 52,000,000 pounds. The resulting increase in the wealth of the country enabled it to support the immense burden of taxation consequent upon the long-continued state of warfare which followed upon the French Revolution.

With the crash of the Napoleonic empire there came a marvelous display of commercial activity in Great Britain, coincident with the development of its textile industries under the factory-system of production. The vital energy of the people so employed was then freed from the drudgery of turning the spinning-wheel and throwing the shuttle, by the substitution of machinery driven by an inorganic force. But, still, the coal from which this force was obtained was transported from the mines by rivers and canals with motive power derived alone from the vital energy of men and beasts, until the steam-power that had raised the coal and pumped the mines and driven the looms, was experimentally applied to railway transportation.

Early Origin of Railways

The early application of steam to land-transportation, in advance of other countries, added immeasurably to the primacy in commerce, mining and manufactures already attained in England. The railway itself was not a novelty. It originated in obscurity in the 17th century, when thousands of carts were employed in carrying coal from the collieries to the barge-ports. As late as 1813, there were collieries that had each from 600 to 700 carts in this service. The surface of the roads over which this traffic was conducted was so cut up, in bad weather, that the ordinary loads of seventeen hundred weight were at such times greatly diminished. Wooden cart-wheels were fitted to run on short timbers laid on cross-ties or sleepers. Then, where the wear was heavy, on steep grades or on sharp curves, the surface of these timbers was protected by strips of wrought-iron, for which cast-iron rails with an inner flange were subsequently substituted. In 1788, these were replaced by the "edge-rail" and the flanged wheel, and the modern railway was born. To the invention of this simple device by William Jessop, is due the substitution of mechanical power in land-transportation throughout the world.

The wooden railway, though at first a mere adjunct to the collieries, became gradually utilized as an iron railway, by the canal companies themselves, as feeders from other points of production. The Trent and Mersey Canal Company obtained parliamentary authority in 1776 for the construction of such a "railway," 3½ miles in length, to some quarries and, in 1802, for three others to potteries. By 1812, the railways of this character in South Wales amounted to a total length of over a hundred and fifty miles. This mode of transportation was further developed under the name of "dram-roads," as a link between canal-levels, to avoid the construction of intermediate lockage. Between 1801 and 1825, twenty-nine of such roads were authorized by Parliament. One of them, 34 miles in length, overcame an elevation of 990 feet.[1]

The next stage of railway development was in the construction of railways independently of canal-service. The first line of this character was undertaken by the Surrey Iron Railway Company, chartered in 1803, to build a line from the Thames for a distance of nine and a half miles "for carrying coals, corn and all goods and merchandise to and from the Metropolis."

The canal companies had by this time attained great prosperity. Shares of the par value of £100 were sold at £570 to £1350, and, in the case of the Trent and Mersey Canal Company, at £2300! In 1824, when the Loughborough Navigation Company paid a 200 per cent. dividend, its shares were quoted at £4700! As they perceived the probable effect of steam-railway competition upon their original investment of £14,000,000,

[1] Pratt, "Inland Transport and Communication in England," p. 222.

the canal companies combined with the great land-owners in opposition to every application for a railway charter. The contests before parliamentary committees were waged so vigorously that it became the most lucrative practice of the legal profession, and the cost of these preliminary proceedings absorbed millions of pounds of railway capital. But, as the railway construction continued, canal-revenues diminished so seriously that the canal companies kept up their opposition mainly to be bought off. The last internal canal was completed about 1834, and the canal-system of Great Britain is now controlled by the railway companies.

Advent of the Locomotive and the Railway Epoch

The railway, in its origin, was but an accessory to mining operations, devised to facilitate the removal of their products to the nearest waterway. In its primary application to a road-bed, it was merely a surface of timber; in fact, only a cheap substitute for a macadamized road. The only advantage which it offered as a means of communication over the turnpike, was in the reduction of the rolling-friction between the wheels and the road, but this advantage was diminished when the same form of tires could not be used upon both kinds of roadway. While this development of the railway as an adjunct to mining-operations had been going on for perhaps fifty years, there had been contemporaneously a series of experiments with steam as a motive force. So it was that the two inventions that were to revolutionize commerce and to spread European civilization over the face of the earth were brought to light in the same country — England, which was at the time the leading nation in industrial enterprise and in the freedom of individual activity from government control. In England, then, the iron way and the steam-engine were brought into proximity at the coal-mines. The steam-engine hoisted the coal to the surface, but its carriage on the iron way was still performed by the animal power which had done that service on other roads from time immemorial.

In 1813, Blackett discovered, experimentally, that a carriage could be propelled on a railway by the machinery which it carried; the power being transmitted to wheels fixed on the axles and the traction exerted simply by the adhesion of the wheels to the rails. As the flanged wheel had made the railway possible, so did this discovery solve the problem of the application of mechanical power to traction on the railway. When, in 1814, George Stephenson built his first locomotive, the locomotive superseded the draft-horse. Thus an instrumentality had been devised for land-transportation, with a capacity for traction, endurance and speed that was not restricted by the limitations of muscular power or of vital force. But the advent of the railway era really dates from the charter of the Stockton and Darlington Railway Company, in 1821. It was on this railway, after twenty miles of the line had been worked by horse-power, that Stephenson operated the "Locomotive," in 1825. The Liverpool and Manchester Railway Company was chartered in the following year, and on the line of this company, in 1829, Stephenson, at the Rainhill competitive trials, scored as a winner, with the "Rocket," of historic fame.

Great are the consequences that have since ensued. The advance of civilization, the elevation of the great body of population in education and in comfort, the opening of vast uninhabited regions to immigration and prosperity, have followed upon the facilities for intercommunication afforded by the use of steam-power in transportation. The cheapness of railway service and its capacity for indefinite expansion have furthered the concentration of manufacturing industries on a large scale, at points of convenient access for raw materials and for distribution of their products. Railways have made it possible for cities to increase in population beyond the fabled magnitude of Babylon or Rome, by bringing the resources of distant regions to the support of the toiling millions, who also rely upon them for the daily journeys between their homes and their work. Nor should we overlook the diminution in loss of life, and in suffering from starvation, that has been effected by facility in railway communication. In Hindustan, for example, in seasons of short crops, famine has been averted by the transfer of food-products from regions of abundance to those of scarcity, which could not have been accomplished but for the construction of its extensive railway system. All these blessings to the entire human race have resulted from the greater economic efficiency thereby attained in the application of their labor to other pursuits than bearing burdens, or driving draught-animals.

Nor can any appreciation of railway transportation, as a factor in social efficiency, be complete that does not include a consideration of its value for national defense.[1] When the history of the great European War is written, it will disclose the magnitude of the railway operations by which vast armies, with their many accessories, were hastened across Central Europe from one hostile frontier to another of the German Empire, thus virtually doubling its military strength. Similar illustrations will exemplify the efficiency displayed by the British railway managements in the speedy concentration and transmission of the Expeditionary Corps to the relief of France at the first outset of war, and also in the facilities generally afforded for the continuous supply of munitions and for the movement of heavy siege-guns, as well as for the rapid and comfortable transfer of the sick and wounded to suitable hospital accommodations, far from the turmoil of battle. This experience has been advantageously applied to securing coöperation between our own military and railway administrations.

The discoveries made by ocean-voyagers, in the fifteenth century, constitute an epoch in the extension of international commerce. That

[1] See "Our Railways and National Defense," C. O. Haines, North American Review, September, 1915.

commerce, however, was much restricted by inefficient means of land-transport, until the application of steam as a motive force gave a fresh impetus to communication between regions as effectually separated by mountain ranges and by deserts as others were by the broad seas. Even the international commerce conducted by ocean-steamers would be of much less magnitude, were it not for the service performed by railways, in gathering together the products of far interior regions and in concentrating them at ports convenient for transshipment.

Railway Aid to National Development

However much the human environment in which railway operations are conducted, may be influenced by political and commercial conditions, there yet remains a field of activity based upon that complexity of habits and customs which marks the gradations from barbarism to civilization, and which may be considered as purely social. In this social environment have been developed the primal instincts of the human race, so fundamental as to persist in spite of political and commercial conditions; yielding in form to physical conditions, though not in substance. You may cross the seas to other climes, but human instincts remain everywhere the same. Differences in the social environment are due to the reaction of these instincts upon a different physical environment. Perhaps in no other physical environment has this principle of sociology been made more manifest than on the American continent, and especially in that region which now constitutes the United States. In no other part of either of the Temperate Zones was there so vast a region, so bounteously provided with natural resources, and yet so little exploited by man. It was half a continent, stretching from ocean to ocean. Upon its eastern coast, it became thinly colonized by migrants from every class of society in western Europe. These colonies were planted apart, at distances sufficient to permit of their independent expansion, restricted only by physical limitations and by the vicinage of tribes of barbarians, few in number and without a common organization. But the affiliations of these colonies with the stocks whence they had respectively sprung, militated against any common organization among themselves. They not only had to defend their homes from Indian raids, but also from invasion by each other. The local antagonisms thus engendered persisted far into the future, and have left ineffaceable shades of difference in the habits and customs of succeeding generations.

The cradling of a nation on this distant coast was affected by this very political environment, first in the concentration of the military strength of the British settlers by the colonial wars of Great Britain with France and Spain, and afterward in the united resistance of British colonists themselves to ill-advised legislation by the oligarchies which still administered the parental government. The hitherto loosely organized confederation of these colonies became thereby moulded into an independent and compact federation of states — an unique phenomenon in political evolution. The leaders in this experiment, having cast off the shackles of a government of the Many for the benefit of the Few, rested the substructure of a government by the Many for the benefit of All upon the habits and customs of the people, as developed by the reactions of their primal instincts upon their peculiar environment — and the United States of America was launched upon the sea of destiny.

Insignificant as this new-born federation was, in population and resources, its influence was felt across the Atlantic, as a ferment in the body-politic of France, in the overthrow of the absolute monarchy which had for centuries oppressed the common people of that fair land and in the ever continuing march of democracy through Western Europe. Animosity toward the aristocratic government of Great Britain and sympathy with the French people, sentiments inherited from the rebellious colonists, smoothed the way for the acquisition of the Mississippi Valley and of an ancillary claim to the little known regions that lay still farther westward, even to the Pacific coast. This was the initial step in the progress of the United States to prosperity. Its people were now able to widen their field of activity untrammelled by political conditions and restricted only by physical limitations. The principal restriction of this character was the series of mountain ranges, parallel with the Atlantic coast, that separated the territory of the original colonies from the vast and fertile region which was now the common property of the people who were henceforth to be distinguished as Americans, *par excellence.*

Railway transportation in England was introduced into populous regions with large volumes of traffic that had hitherto been distributed by wagon-trains and stage-coaches over excellent roads, or by transports along the seaboard and the many navigable streams and canals. These systems of communication had become efficiently adapted to the environment in which the system of transportation by rail was being developed. It was, therefore, primarily intended to compete for traffic already in existence. Capital was abundant and was readily attracted to railway undertakings by the financial success that had resulted from the operation of the earlier experimental lines. Consequently, the railways of Great Britain approached, in the first stages of their development, nearly in efficiency to what they are to-day. This was, in general, the case throughout western Europe, where British methods were closely followed.

The railroad system of the United States, though developed contemporaneously with that of Great Britain, originated in a far different environment. It had been preceded by no highway system, unless the National Road over the Alleghanies may be so considered. The Atlantic seaboard was served principally by sail-vessels on the few navigable streams. Steamboat service had been more extensively developed on the Great Lakes and on the Mississippi River system, and the intercommunication by canal between these regions and with the seaboard, was just beginning to assume importance, when its further growth was arrested by the evident superiority of the rapidly extending system of transportation by rail. Capital was locally deficient, and engineering education and experience had been directed mainly to military purposes and to surveying the public lands. Little of either of these requirements had been derived from European sources, as transatlantic communication was restricted and infrequent. As the country was virtually devoid of roads, the railroads preceded them; in fact, they preceded civilization. They were not intended to care for existing traffic, but to create it and to populate vast uninhabited areas; for they were extended into regions still in a primitive state, verging on barbarism.

Slowly, the wagons of the pioneers toiled along tracks before untrodden, save by hunters, through mountain passes and dense forests ambushed by Indians, to reach the land of promise. Better ways of communication must be had for the latent resources of the Mississippi Valley to be speedily developed, for the wilderness to be replaced by fruitful fields, and for commercial centers to be established wherever the environment favored the concentration and distribution of commodities. Northward, the Great Lakes provided a navigable route to the Atlantic, barred, however, by the Falls of Niagara. The Ohio and Mississippi rivers provided a route southward to the Gulf of Mexico. The one was soon dotted with sailing vessels and the other with flat-boats and rafts, but neither directed the current of commerce to the Atlantic Coast. The principal business centers on that coast, New York, Philadelphia, and Baltimore, became alive to the restrictions of their physical environment and each strove to overcome them by the construction of artificial waterways. The most efficient of these was the Erie Canal, which, in connection with the Hudson River, gave to the city of New York commercial preëminence over its rivals. Other canals were constructed as feeders to the principal lines, as also to connect the navigable waters of the Mississippi Valley with the Great Lakes. The efficiency of this system of internal waterways was substantially increased by the introduction of steam-navigation, which rapidly attained a magnitude unparalleled elsewhere for many years.

It was just at this period that the means then in use in England for transporting coal by rail from the collieries to the points of embarkation, was adapted there to the purposes of general commerce; though, even in that country, the railway was then in an experimental stage, but with the promise of greater economic efficiency than was afforded by its excellent turnpikes. In the United States, the idea of railway transportation was quickly seized upon by intelligent leaders of public opinion in the seacoast cities less favored than New York with natural water-routes to the interior, and, almost contemporaneously, Boston, Philadelphia and Baltimore began developing experimental railways, independently of English experience, and while traction by animal power was yet to the fore.

The application of steam-power to land-transportation, in the United States, rather lagged behind its use on waterways, though it proceeded by almost equal steps with the progress made in Europe; and horse-drawn cars owned by private individuals competed with steam-driven trains on the main railway line out of Philadelphia as late as 1844. The possibilities of railway transportation were not apparent until the service respectively performed by the road, the vehicle and the tractor had become controlled by the same management. Then the future thus opened out to communities longing for intercommunication, yet restricted by physical limitations, was so obvious as to awaken general interest in the promotion of railway undertakings.

Political limitations also impeded railway construction. The constitutional powers of the Federal government had been restricted by adherence to the doctrine of State sovereignty. As a consequence, one entire commercial route could not be covered by a single charter, but only piecemeal, by separate grants within the limits of each State, and with differing privileges. Any extension of the control of one company over railway operation in an adjoining State was, therefore, a matter of comity, and not of chartered rights. Investments in these companies were affected, as to privileges and obligations, by legislation, varying in the several States, which obstructed mergers and consolidations essential to financial stability, and which has embarrassed the operation of important railway lines even to the present time.

The amount of unemployed capital being inadequate even for ordinary business-purposes, private corporations were hindered in undertaking works of public improvement, and this induced their prosecution through the intervention of municipalities, of the States, and of the Federal government; to some extent, indeed, with aid from taxation, but principally by pledging the sales of public lands, directly or indirectly, for loans obtained in Europe. The improvement thus effected in the means for internal communication prepared the way for gradually increasing migration into the Mississippi Valley, and for increasing the national wealth from undeveloped resources. It was the labor of European immigrants, as well as the capital procured from Europe and invested in this vast public domain, that laid the foundation for our national prosperity and for the subsequent development of our railway system.

Growth of Railway Building in the United States

The first railroads in the United States were tramways, operated by horse-power. The Quincy tramway, three miles in length, was built in 1828, to convey stone for Bunker Hill Monument from the quarry to tidewater; and the Mauch Chunk tramway, in 1827, for transporting coal from the mines to the Lehigh River. The first use of a locomotive was on the Delaware & Hudson Coal Company's road, at Honesdale, Pa., in

August, 1829. Work had begun on the Baltimore & Ohio Railroad in 1828, but it proceeded so slowly that but 13 miles had been completed in 1830. The Washington Branch was opened in 1835. The first road in this country, that was chartered specifically for steam-operation, was the Charleston & Hamburg Railroad from Charleston, S. C., to Hamburg on the Savannah River, opposite Augusta, Ga., a distance of 138 miles. It was opened in 1831 and was, at that time, the longest railroad in the world.

The first trip of a locomotive on the Mohawk & Hudson Railroad from Albany to Schenectady was made in August, 1831. The extension to Utica was completed in 1836, and to Buffalo in 1842, seventeen years after the opening of the Erie Canal. By 1835, there were 265 miles of railway line in operation in Pennsylvania. In 1835, Boston was connected by rail with Providence, Lowell and Worcester, and, by 1841, with the line extending westward from Albany. In 1838, the waters of New York Bay were connected with Philadelphia by the completion of the Camden & Amboy Railroad, and a land-route by steam was established between New York and Washington.

In 1851, New York City was connected with Albany, and the Erie Railroad was opened from Piermont on the Hudson River to Lake Erie at Dunkirk. In 1852, the Baltimore & Ohio Railroad was completed to Wheeling, and the Pennsylvania Railroad to Pittsburgh. In 1848, Cincinnati was connected with Lake Erie and, in 1852, Pittsburgh with Cleveland. The Michigan Central Railroad from Detroit, and the Michigan Southern Railroad from Toledo, reached Chicago in 1852, and the link between Buffalo and Cleveland was completed in 1853; but the Pennsylvania Railroad connection by Fort Wayne was not opened until 1858.

Chicago secured its first rail-connection to the Mississippi River by the Rock Island Railroad in 1854, another by the Galena & Chicago Union Railroad in 1855, and by the Chicago, Burlington & Quincy Railroad, in 1856. In the same year, the Illinois Central Railroad connected Dubuque and Chicago with the junction of the Ohio and Mississippi rivers at Cairo. In 1857 the line was opened from Milwaukee to the Mississippi at Prairie du Chien, and another at La Crosse in 1858. In 1859, the Hannibal & St. Joseph Railroad crossed the State of Missouri to the Missouri River, and the Chicago & North-Western Railroad crossed Iowa to Council Bluffs, opposite Omaha, in 1867.

Prior to 1850, the South Atlantic railroad system had been developed parallel with the coast for 320 miles, from the Potomac River at Acquia Creek to Wilmington, N. C. During the same period, a local system had been likewise developed in upper South Carolina, connecting with the South Carolina Railroad at Columbia, and, in 1853, the line north of Wilmington was connected also with the South Carolina Railroad at Kingville. The Georgia Railroad had been opened from Augusta to Atlanta in 1839, and in the next year the Georgia Central Railroad was completed from Savannah to Macon. It was shortly afterward connected with Atlanta by the Macon & Western Railroad, and, in 1854, through Columbus, on the Chattahoochee, to a connection with Montgomery on the Alabama River. Atlanta was connected with Chattanooga in 1850, and with Montgomery in 1853. Chattanooga was connected with Nashville in 1854, with Memphis in 1857, and, through Nashville, with Louisville in 1859. In the same year, Mobile was connected with the Mississippi River at Columbus, Ky., and New Orleans with the railroad system south of the Ohio River at Jackson, Tenn. In this same period, an interior system had been extended from Alexandria, Va., southward to Chattanooga, and a connection had been made from Portsmouth, Va., through North Carolina to Charlotte and the lines in upper South Carolina. This is a general outline of the railway system of the United States at the outbreak of the Civil War.

In 1837, there were 20 miles of railroad in the United States; in 1840, 2818; in 1850, 9021; and in 1860, 30,914.[1] The increase per decade was about as follows:

	Mileage	Per Cent.
1850	6,203	220
1860	21,614	238
1870	22,279	72
1880	40,435	43

The population of the United States, which in 1800 was about 5,000,000, had increased to 17,000,000 in 1840, and to 31,000,000 in 1860, from which is seen the relative magnitude of the railway system of the United States to its population at the beginning of the Civil War, that momentous epoch in the history of our country. The next decade was virtually devoted to the disintegration of the previous social order and to its reconstruction upon a different basis. It was during this period that railway construction was undertaken upon a far more extensive scale than had before been practicable. The enormous amount of depreciated currency invited its investment in speculative enterprises; the concentration of unemployed capital for investment was facilitated by bankers and by stock-exchanges; the labor available for works of public improvement had been largely

[1] This estimate is from the Scientific American, May 20, 1909. In June 5, 1915, there appeared in the same publication another estimate as follows:

1845 — 4633 miles; 1855 — 18,374 miles; 1865 — 35,085 miles; 1875 — 74,096 miles; 1885 — 128,320 miles.

Another estimate appears in "The Economic Theory of Location of Railways," by A. M. Wellington, Edition of 1915, page 42; "Revised from Mulhall's Dictionary of Statistics," as follows:

1840 — 2818 miles; 1850 — 9021 miles; 1860 — 30,635 miles; 1870 — 52,914 miles; 1880 — 93,349 miles.

increased by immigration. The whole country, now reunited politically, was reawakened to progress and prosperity, and the people became clamorous for railway extension on almost any terms.

Adventurers seized the opportunity to promote railway construction in regions as yet undeveloped. Their projects were made attractive by promises of the results which were to follow upon their realization; they were furthered by brokers who sought to share their profits, and by bankers who made advances of capital at high rates of interest, until their stocks and bonds could be passed on to confiding investors. Their spoils were garnered from every field that proffered a harvest. Where railways were most wanted, they sought the aid of the State. Legislatures were besieged by lobbyists whose schemes were furthered by the legislators themselves — some of them innocently, others from concealed personal interest; while combinations of promoters secured legislation by mutual support of each other's projects. By these devious ways, the credit of many States was so overtaxed as to place a burden upon their citizens for years afterward.

Railway extension was so stimulated by such methods that, in 1870, there were about 53,000 miles of road in operation; an increase of nearly 22,000 miles, or of 72 per cent., in the ten years which included the Civil War. The new lines were hastily constructed, that the returns from operation might meet the payment of expiring loans and of maturing coupons; and they were scarcely opened for business when, from structural weakness, the cost of maintenance absorbed the most of their earnings. Where two or more lines were extended into common territory, rivalry for its traffic was carried to such excess that the consequent loss in operation made an additional draught upon the revenue from local traffic.

Then came the financial crisis of 1873, partly a consequence of this very situation, that now involved in bankruptcy one-fourth of the total railway mileage, and which seriously embarrassed the older corporations which had been able to weather the storm.

The financial crisis of 1873 culminated in 1878 with 10,478 commercial failures, and liabilities of $234,000,000.[1] In these five years, railroad securities had gradually passed from the original holders to their creditors, and reorganization of the bankrupt corporations was effected as rapidly as foreclosure proceedings would permit. Their finances were now controlled by experienced capitalists, who knew that the reconstruction of their lines was a necessary precedent to their efficient operation, and who were able to provide the means for that purpose. Opportunity was taken to consolidate in a single company the ownership of the separate portions of a continuous trade-route, and for controlling competitive traffic under a single authority by the common ownership of rival corporations. The effect of this regeneration of the railroad situation was made apparent in

[1] World Almanac.

the increase of railway mileage to 93,000 miles in 1880. The accompanying advance to social prosperity was manifested by the current of immigration, which had diminished from 460,000 in 1873 to 138,000 in 1878, and had risen again to 457,000 in 1880.

Transcontinental Systems in the United States and Canada

A distinctive stage in the extension of our railway system was marked by the connection of the Atlantic and Pacific coasts by a transcontinental line. The circuitous route by sea had been supplemented by the construction of the Panama Railroad, opened in 1855, which facilitated commercial intercourse between the Eastern seaports and the newly discovered gold fields of California. The population of that state in 1860 was 380,000; that of Oregon and Washington was but 64,000. This was but a meagre basis for so ambitious a project as the construction of a railway for 2000 miles through a virtually unknown region of deserts and mountains, for the most part occupied by savages, normally hostile to the whites and to each other.

The scheme had been agitated in Congress for many years, though the social isolation of the Pacific coast was manifested in the indifference of its inhabitants to the critical situation of the Union during the Civil War. The possible consequences of a continuance of this isolation emphasized the necessity for binding this remote region to the rest of the country by improved means of intercommunication, and the transcontinental railway project was revived as a patriotic measure.

No railway enterprise of such magnitude had as yet been undertaken elsewhere. Capitalists did not view it favorably, nor was aid from the governments of the older states available, as the proposed lines for the most part traversed the public domain. There was no financial basis for its realization other than that to be obtained from the Federal government. After a protracted debate in Congress, in which the advocates of rival schemes neutralized each other's efforts, a conclusion was reached by a combination among them. The public credit was pledged for each of their projects, together with grants of the public domain that totaled in area the entire territory of the New England and the Middle States, conditioned, however, upon their progressive consummation. This conclusion was reached in 1862, when the Union was ablaze with civil warfare.

The Union Pacific and the Central Pacific railroad companies were first in the field. Notwithstanding the adverse financial conditions and the physical difficulties to be overcome, the construction of their lines was effected with such unexampled rapidity that this transcontinental route was opened on May 10, 1869. The Union Pacific Railroad Company shared the fate that overwhelmed many railway corporations in the financial crisis of 1873, and was for some years under a receivership. The control of the corporation then passed to capitalists who also controlled the

Central Pacific Railroad, the physical condition of its property was brought into a high state of efficiency, and its fortunes were carried to the pinnacle of prosperity.

For twelve years the Union Pacific Railroad afforded the only communication by rail across the continent. Now, there are six other transcontinental lines in the United States and three in Canada.[1] In 1860, beyond the western boundaries of Texas, Arkansas, Missouri, Iowa and Minnesota, there was a population of about 770,000; in 1910, the same region had a population of 8,000,000, with 67,000 miles of railway lines. What more striking example can be cited of the social efficiency of railway operation?

Railway and Water Competition in the United States

Railway transportation, which was originally but the combination of the service of the stage-coach and the carrier's wagon upon a turnpike with an improved surface, has appropriated in its development nearly every advance that has been made in the application of the results of scientific research to the welfare of mankind. This appropriation of almost the sum of human knowledge in a concrete form, has been accompanied by an extension of its field of usefulness over the face of the earth. But nowhere else has the development of railway transportation been so rapid as in the United States, and in no other country are railways operated under more diversified conditions or on so extensive a scale.

As a consequence of railroad competition, rivers that were once commercial highways are now frequented mainly by pleasure craft, and cities which owed their prosperity originally to their situation on river banks, now maintain that prosperity by their railway facilities. The experience of Great Britain in this respect has here been repeated on a larger scale. Even the Mississippi River, the "Father of Waters," has succumbed in the unequal contest. Despite the millions that have been lavished by the Federal government upon its maintenance in navigable condition, the commerce once concentrated upon it and its tributaries, from the vast region which it penetrates, has shrunk almost to a negligible quantity; with the exception of the coal-traffic, or of contributions to the railroads that touch its banks. In 1880, the water-tonnage from St.

[1] The Canadian Pacific Railway Company is the most extensive transportation organization in the world under a single control. Its continuous service extends from the British Isles across the Atlantic Ocean, the American Continent and the Pacific Ocean to ports thousands of miles apart on the Asiatic Coast. The conception and execution of this magnificent undertaking was the work of three great Scotchmen: Sir John MacDonald, Premier of the Dominion; Donald A. Smith, Lord Strathcona; and George Stephen, Lord Mount Stephen. It has been a success, commercially and financially, from the beginning of its operation.

For a more detailed account of the development of the railway system of the United States, see "Problems in Railway Regulation," The Macmillan Co., 1911; also, "When Railroads were New," by C. F. Carter, Henry Holt & Co., 1909.

Louis reached 1,038,000 tons; in 1900, 245,000 tons; in 1911, 191,735 tons. Although $15,000,000 have been spent on the Missouri River, its entire traffic, from Kansas City down, amounted in 1910 to about two car-loads of freight per day. In 1911, the total tonnage of the Mississippi River from St. Paul to New Orleans was estimated at 5,500,000 tons; just the tonnage of Newtown Creek in New York Harbor! Yet about $100,000,000 from the Federal Treasury have been expended upon the whole Mississippi river-system, whose only remaining commerce of importance is the coal-traffic, which in 1906 scarcely amounted to 11,000,000 tons.

Canals are free from many of the disadvantages of river-navigation. At one time, the canal-mileage of the United States had reached nearly 5000 miles, almost double that of Great Britain at its best. Half of the mileage, representing an original investment of over $80,000,000, is now abandoned. The Sault Ste. Marie canals are only auxiliary to the railroads which feed the commerce of the Great Lakes, and the Erie Canal is alone of commercial importance. As the Mississippi River has been maintained in navigable condition at the cost of the Federal treasury, so has the Erie Canal been a heavy burden upon the taxable resources of the State of New York. Since 1882, it has been toll-free and, down to 1906, it has cost the State $56,000,000, or about $163,000 a mile. For about six months in the year, the Erie Canal is closed to navigation. Its commercial value is further limited by its restricted dimensions, which are now being enlarged at an estimated cost of $100,000,000 with, in addition, unsettled damage-claims amounting to $62,000,000.

The cost of maintenance of the Erie Canal in 1909 was $672,000, and its commerce amounted to 1,600,000 tons of way-freight and 436,000 tons of through-freight. In 1914 its entire tonnage was but 1,316,000 tons, equivalent to 72 car-loads of 50 tons daily or to 36 car-loads each way; less than a train-load per day! The tonnage of one train of 50 cars of 50 tons' capacity exceeds the tonnage of three barges on the Erie Canal of 800 tons, and the train can make the trip from Buffalo to New York and return to the elevator in Buffalo in five days. A barge requires six weeks for a similar trip. While three barges are making this trip with 2400 tons of freight to New York, one train of 2500 tons' capacity can make eight of such trips with 20,000 tons. The relative social efficiency of the railroad to the canal is, therefore, as eight to one.

The distance between Buffalo and New York by the New York Central Railroad is 440 miles. The export rates, including elevator service at both terminals, are 5½ cents per bushel on wheat and 4¾ cents per bushel on corn; equivalent, respectively, to $1.83 and $1.70 per ton, or a rate per ton-mile of 3.11 mills and of 3.09 mills.[1]

[1] See "Manchester Ship Canal Stockholders' Association," Statist, July 3, 1915, for a more reliable comparison of the relative commercial value of railways and canals than can be obtained from reports of canals operated as public enterprises.

The Great Lakes bear the greatest burden of commerce of any interior water-system in the world; yet the season of navigation upon them is much shortened by the rigors of winter and, for over seven months annually, the communities upon their shores would be deprived of the facilities upon which their prosperity depends, were it not for their railroad connections. As a fact, the commercial service upon the Great Lakes is maintained principally as a feeder to these connections. The coastwise service of the Atlantic Seaboard is similarly associated with railroads from seaports into the interior, that thus maintain competition with the all-rail lines radiating from the principal commercial centers. The transcontinental lines have now to cope with the Panama Canal for the traffic between the East and the West. In this competition they are handicapped by restrictions imposed by Federal legislation. It would be interesting to see the result, were they permitted to meet that competition with a free hand.

CHAPTER II

RAILWAY EFFICIENCY

Increase of Efficiency with Increase of Traffic

In the period of financial embarrassment and competitive strife that followed upon the commercial crisis of 1873, the maintenance of roadway and of equipment had been neglected on the greater part of the railway system of the United States. The service had so deteriorated as to be inadequate for the requirements of the increasing traffic. In fact, it may be asserted that the railroads in the United States, as a system, were in a state of disintegration physically as well as corporately. Economic efficiency in their operation, as a whole, really began in the stage of reconstruction that thereafter followed. Bitter experience in the previous period had prepared the way for better methods, but only after the financial crisis had passed was it possible for the means to be obtained for putting them into effect.[1]

The subsequent improvement in the general efficiency of our railway system is made apparent in the statistical reports of the Interstate Commerce Commission. The railroad mileage, which amounted to 93,000 miles in 1880, had increased by 1890 to 166,000 miles; 73,000 miles additional or 78 per cent. in ten years. In the succeeding decades, there has been no such increase. By 1910, the mileage was 240,000 miles; in 1911, 242,000; in 1912, 245,000; in 1913, 247,000; in 1914, 252,000. In 1881, Mr. Edward A. Atkinson estimated that our railway mileage would reach 209,225 miles by 1909, while the actual mileage at that date was 192,556 miles. In 1911, it was estimated that the new construction might average 5000 miles per annum,[2] but the total increase from 1910 to 1914 averaged but 3000 miles per annum.[3] The mileage per 100 square miles increased from 7.97 miles in 1909 to 8.48 miles in 1914, while the mileage per 10,000 inhabitants decreased from 26.20 to 25.64 miles. The diminishing increment in railway extension has been attributed to the approaching adequacy of mileage in the more populous regions, to the cessation of

[1] For a description in detail of the growth of the railroad system of the United States, see "Problems in Railway Regulation."

[2] "Problems in Railway Regulation," p. 301.

[3] See Appendix I, Table II.

competition by rival corporations due to rate-fixing by the Interstate Commerce Commission, and to the increasing difficulty in obtaining capital for this purpose upon remunerative terms.

Volume of Traffic by Territorial Districts in the United States

The railway system of the United States may be regarded as divided by differences in physical and social environment into three great territorial districts. One of these, which includes those States that are bounded by the Potomac and Ohio rivers on the south and by the Mississippi on the west, but exclusive of Wisconsin and the railway lines from Chicago westward, may be termed the Eastern District. The States south of the Eastern District and east of the Mississippi, may be termed the Southern District; and the remaining portion of the United States, the Western District. As so divided, the Eastern District contained, in 1914, about 61,000 miles of line; the Southern District, 51,000 miles, and the Western District, 140,000 miles.[1] The ratio of mileage of line to area of territory in each of these districts was approximately as follows:

District	Mileage	Square Miles	Per Mile of Line
Eastern	61,184	375,715	6.16
Southern	51,098	449,696	8.70
Western	139,948	2,201,379	15.90
United States	252,230	3,026,790	12.11

The increase in mileage from 1911 to 1914, in these districts, was as follows:

Eastern District	303 miles	0.5 per cent.
Southern District	2,379 miles	4.9 per cent.
Western District	5,369 miles	4.0 per cent.
United States	8,051 miles	3.3 per cent.

It may be added that the Eastern District of the United States is now better provided with railroad mileage than is Great Britain.

The transportation service performed by this mileage in 1890 was measured by 76,207 millions of tons carried one mile, and by 11,847 millions of passengers carried one mile; and in 1913 by 301,398 millions of ton-miles and 34,375 millions of passenger-miles. This increase of 295 per cent. in freight-traffic and of 191 per cent. in passenger-traffic was accomplished with an increase of only about 50 per cent. in line mileage. The density of traffic in 1890 was at the rate of 487,000 ton-miles and of 75,000 passenger-miles per mile of line. In 1913, the density of traffic had increased to 1,245,000 ton-miles and 143,000 passenger-miles. Per mile of

[1] See Appendix I, Table III.

line, the efficiency of our railway system had increased in 23 years by 153 per cent. as to freight-traffic, and by 90 per cent. as to passenger-traffic.[1]

The volume of traffic in each of these districts was as follows:

Districts	Freight Traffic Millions of Ton-miles	Passenger Traffic Millions of Passenger-miles
Eastern	154,173	16,397
Southern	48,543	4,489
Western	98,682	13,689
United States	301,398	34,575

From the above statement, it will be seen that one-half of the freight-service of our whole railway system, together with nearly one-half of the passenger-service, was performed by the 61,184 miles of line in the Eastern District, or by less than one-fourth of the entire mileage. The Southern District performed one-sixth of the freight-service and one-eighth of the passenger-service with 51,098 miles of line, or about one-fifth of the total mileage, and the remaining one-third of the total freight-service, together with three-eighths of the passenger-service, was performed by the lines in the Western District of 139,948 miles, or a little more than half of the entire mileage.

The relative service performed in these districts may perhaps be more readily appreciated by a comparison of the density of traffic per mile of line, as follows:

Districts	Freight Traffic Ton-miles	Passenger Traffic Passenger-miles
Eastern	2,473,764	264,498
Southern	1,063,094	98,236
Western	736,959	102,227
United States	1,245,158	143,067

Here it will be seen that the density of freight-traffic in the Western District was less than one-third of that in the Eastern District; that the density of passenger-traffic in the Southern District was about three-eighths of that in the Eastern District; and that in the Eastern District the density of both freight and passenger traffic was double the average density

[1] Traffic Statistics for 1914

	Number	Density per Mile of Line
Millions of Ton-miles	288,319	1,144,000
Millions of Passenger-miles	35,258	140,000

of the whole system. These simple facts indicate the wide differences between the several districts as to transportation conditions and also the necessity for difference of treatment in the regulation of railway affairs within their respective borders.[1]

In each of the territorial districts, certain railway systems predominate; as in the New England States, where the New Haven system virtually controlled the traffic situation until its disintegration under judicial procedure. In the remainder of the area included in the Eastern District, the trunk-line traffic between the Atlantic Coast and the Mississippi River is mainly carried by the New York Central, the Erie, the Pennsylvania and the Baltimore and Ohio systems, as also the vast traffic with the Great Lakes. The anthracite-coal traffic is participated in by the Philadelphia and Reading, the Lehigh Valley, the Delaware, Lackawanna and Western, and the Delaware and Hudson systems.

The currents of traffic in the Southern District are physically separated by the Alleghany range. The service east of that range is principally performed by the Southern, the Atlantic Coast Line and the Seaboard Air Line systems, whose freight-traffic has been developed from Norfolk as a base, and their passenger-traffic through Washington. A large part of the traffic that parallels the Mississippi River is conducted by the Louisville and Nashville, the Mobile and Ohio, and the Illinois Central systems. The Chesapeake and Ohio and the Norfolk and Western systems are principally engaged in the important traffic of the coal-regions tributary to their lines, while other lines are occupied with the business from the South Atlantic ports into the interior.

In the vast territory of the Western District, there are important currents of traffic identified with the grain-producing region of the Great Prairies and the mineral-producing region of the Rocky Mountains, as well as the transcontinental traffic. In all of these regions, the pioneer systems across the continent maintain their prestige. The Union Pacific and the Southern Pacific systems, long under a common control, are now separated. The Atchison, Topeka and Santa Fé system is a powerful rival for Cali-

[1] Traffic Statistics, 1914. Millions of Miles

Districts	Freight Traffic	Passenger Traffic	Compared with 1913		
			Freight		Passenger
			Increase	Decrease	Increase
Eastern	144,428	16,649		9,745	252
Southern	50,131	4,698	1,588		209
Western	93,760	13.911		4,922	222
United States	288,319	35,258		13,079	683

Traffic in the Southern District was apparently less affected than elsewhere by the unfavorable conditions that prevailed in 1914.

fornia business, and the Missouri Pacific has recently opened an independent route to San Francisco. The traffic to the more northern Pacific ports was in the hands of the financial combination controlling the Great Northern, the Northern Pacific and the Chicago, Burlington and Quincy lines, until the Chicago, Milwaukee and St. Paul system was extended to Seattle. These several systems compete for the traffic of the Great Prairies and the Rocky Mountain region with the Chicago and Northwestern, the Chicago and Alton, and the Chicago Great Western railroads. With the development of ocean-traffic at New Orleans and Galveston, stimulated by the opening of the Panama Canal, there is an increasing flow of business from the prairie-region to the Gulf of Mexico, in addition to the local products of the great state of Texas. In each of these territorial districts, there are other important lines which share, to some extent, in the through-traffic between them, but which are principally engaged in business of a more local character.

Mileage and Tonnage

The total railway mileage of the world in 1914 was approximately 714,000 miles, of which the mileage in this country was about 36 per cent. Of the total world mileage about 30 per cent. was state-owned, lying principally in colonial possessions and in Continental Europe.[1] It would be of interest to compare the service which our railway system performs with that performed elsewhere, but statistics adequate for that purpose are not available. It is, however, the consensus of opinion that nowhere else is freight-traffic so efficiently conducted. As was impressively stated by Mr. Seth Low in the arbitration proceedings in the Train Employees Case, "at the present time a ton of freight is moved in the Eastern territory more than three miles for the value of a postage stamp."

When we think of the daily service thus performed in railway operation in the United States alone, and attempt to estimate, for the entire world mileage, the number of years of labor of men and animals that would be expended in transporting the tonnage of commodities and the number of travelers that are carried for distances running up to thousands of millions of miles in a single day, we feel as unable to arrive at an adequate conception of the vital energy that would be thus required as to measure the cosmic energy displayed in the motion of the stars in their courses. Still, some notion may be formed of the value of railway service to communities and nations from estimating the amount saved in interest alone by speedy transportation.

The tonnage of our railway systems in 1912 was about 1,145,000,000 tons, and the average haul was about 263 miles. This distance could not be covered by draft-animals, on an average, in less than eight days. Therefore, it would have taken eight years to accomplish by animal power

[1] See Appendix I, Table I.

that which is accomplished in one year by railway transportation. This is a saving of seven years in time, and in interest on the value of this amount of tonnage in transit. At an average value of ten dollars per ton, the total tonnage would represent an investment of $10,000,000,000, on which the annual interest at five per cent. would be $500,000,000. A saving of seven years' interest at this rate would amount to $3,500,000,000, which represents approximately the relative efficiency of railway transportation to that of carriage by draft-animals in the saving of interest alone on the value of goods in transit, an amount that is virtually an annual increment to the capital so invested.

Electrification of Railways

The characteristic feature of railway service is the production of power for traction from inorganic forces, and its application to the movement of vehicles by rail. Tractive power for this purpose had been obtained solely from the direct application of the expansive properties of water in the form of steam, until inventive genius devised the means for the application of electricity to the same purpose.

The commercial application of electricity to railway transportation began in 1887–88, with the introduction of the trolley system on the street-railways of Richmond, Va., by F. J. Sprague. The electric railway, operated on the third-rail system, at the World's Fair in Chicago, in 1893, spread an appreciation of its efficiency throughout the world. In that year, the first franchise for the operation of a railroad solely by electricity was granted to the Northwestern Elevated Railway Company of Chicago. The development of multiple-unit control[1] by Sprague, in 1895–98, led to the general introduction of electric motor-cars on the elevated lines in Chicago and, after 1902, in New York City also. In 1894, the first interurban railroad specially constructed for electric traction was put in operation between Cleveland and Akron, Ohio, a distance of 35 miles. The transmission of high-tension alternate current, inaugurated in 1895 by Tesla, in connection with the generation of electric current by water-power at Niagara Falls, resulted in its application to lines of considerable length. From that time, the electrification of steam-railroads became a commercial proposition. Its earliest application was in 1895, in the conversion of the Nantasket Branch of the New York, New Haven and Hartford Railroad into a trolley line. This branch was seven miles in length with sixteen miles of track, operated only in summer. The first interurban electrification of a steam-road was undertaken also by the New York, New Haven & Hartford Railroad Company, in 1902, in the conversion of a branch-line between Providence, Warren and Fall River, with 38 miles of track.

The experimental substitution of electric tractors for steam-locomotives was made in 1895, in the operation of the Baltimore Belt Line Tunnel,

[1] The control of the motors in several cars from one place on the train.

covering 7.4 miles of track on the Baltimore & Ohio Railroad, because of the insufficient ventilation of the tunnel. For the same reason, the New York Central & Hudson River Railroad Company was required by legislation in 1902, to supersede steam on its terminal lines in New York City by some other mode of traction. As the company was preparing at that time to remodel the Grand Central Station, it was determined to carry out a scheme of electric traction in a suburban district extending for about 30 miles out, on both the Hudson River and the Harlem lines. As portions of these lines were used jointly by the New York, New Haven and Hartford Railroad Company, that company likewise decided to extend the use of electric traction to Stamford. This was the first example of heavy trunk-line terminal operation for all-passenger-trains, and was initiated solely as a police measure at a time when no apparatus suitable for such work had been invented. Up to this time, the only electric roads, other than city or suburban lines, were magnified trolley-roads on the multiple-unit or motor-car system. But, two years after the work of electrification of the Grand Central terminal lines had been undertaken, the management of the New Haven road determined for the first time the efficiency of electric energy, with appropriate equipment, in the operation of the heavy passenger and freight service of a trunk-line steam-railroad. Meanwhile, the Pennsylvania Railroad management had entered upon the construction of a system of subterranean and submarine lines from New Jersey into Manhattan Island and to a connection with the Long Island Railroad. Between the Westinghouse and the General Electric companies, apparatus and equipment were perfected which were adequate to these vast undertakings, including the electrification of the Hudson River Line to Harmon, a distance of 34 miles, to White Plains on the Harlem line, 24 miles, and the New Haven line to the city of New Haven, 72 miles from Grand Central Station.

In January, 1907, a suburban service with motor-car trains was inaugurated on the Harlem line to Woodlawn, 13 miles. By July, electric tractors were in use for through-passenger service on all lines in the terminal district of six miles, and on the New Haven trains to Woodlawn, where a change was made from the third-rail to the overhead-wire system which had been adopted on the New Haven line, and which was then extended to New Rochelle, three and a half miles farther. In October, this service was extended to Stamford, 33½ miles from Grand Central Station, and this was then the longest mileage operated by electricity on any trunk-line railway in the world. In March, 1910, through electric service on the Harlem line was extended to White Plains, 12 miles beyond Woodlawn: but local passenger-trains on the Hudson River line had been operated by electricity to Yonkers since August, 1908. It was only in 1910 that electric service for all-passenger-trains was completed to the limit of the electrically operated district on the Hudson River line at Harmon. In March, 1913, the electrification of the New Haven lines had been completed to the city of New Haven. By the summer of 1914, the New York, New Haven and Hartford Railroad Company was operating by electricity a six-track line to Stamford and a four-track line to New Haven, including intermediate branch-lines and freight-yards, for all classes of traffic. This system is the most extensive substitution of electricity for steam on any railway with heavy traffic. Including joint-trackage and controlled lines, it covers 112 miles of line with 633 miles of track.

The electrification of the lines of the Pennsylvania Railroad Company in and around New York City was incidental to its policy of interchanging directly the traffic hitherto interrupted by the isolation of its city terminals by the intervening estuaries of the Hudson River and of the East River. Begun June 10, 1903, this great undertaking was opened for through-traffic on November 20, 1910. It then extended from Harrison, N. J., to Jamaica, Long Island, 16½ miles. From the tunnel-portal in New Jersey to that on Long Island, the distance is 5.3 miles. Included in that length of line are parallel river-tunnels of 6.8 miles and land-tunnels of about equal length. It connects with the Long Island system, which is still the most extensive conversion of a steam-road for handling suburban traffic by multiple-unit motor-car trains. It has electrified four-track, six-track and eight-track lines with a total trackage of about 250 miles. This system is now connected with the New Haven lines at Port Morris by a four-track road, 4½ miles in length, crossing the three passages from the East River into Long Island Sound. The completion of this project affords electric service from Newark to New Haven, a distance of 85 miles, being the longest continuous and total electric service of such magnitude on any electrified steam-lines.

Taken as a whole, the electrification of the steam-lines converging on New York City, together with the other engineering work connected with it, constitutes the greatest enterprise in railway construction that has ever been undertaken. Initiated in 1903, it has been carried virtually to completion in eleven years, at a total cost to the Pennsylvania Railroad Company of about $160,000,000, of about $40,000,000 to the New York, New Haven and Hartford Railroad Company, and of probably not less than $100,000,000 to the New York Central & Hudson River Railroad Company. These companies have also expended millions in purely experimental research, while the rapid and extensive development of the several branches of engineering service has made that immediate region, including the New York Subway system, the source of information upon which railway managements throughout the world have based their subsequent undertakings.

In 1906, the West Jersey & Seashore line of the Pennsylvania Railroad system was electrified for 65 miles from Camden to Atlantic City; this being the first instance of the substitution of electric traction for main-line passenger-service. Since Sept. 11, 1915, the suburban lines of that system have been operated electrically for twenty miles from Broad Street Station in Philadelphia westward to Paoli. In 1907, electric service was experimentally introduced upon a division of the West Shore Railroad between Utica and Syracuse and also upon a section of the Rochester Division of the Erie Railroad, as tests of its efficiency in fostering local passenger-traffic on steam-railways. In 1910, an important electrification for local passenger-traffic was completed upon the suburban lines of the Southern Pacific Railway Company centering upon San Francisco.

In May, 1908, the Grand Trunk Railway tunnel under the St. Clair River at Sarnia was operated electrically, on account of its poor ventilation. For the same reason, in July, 1909, a section of four miles on the Great Northern Railway was electrified, to include the Cascade tunnel, 2.6 miles in length; and on March 8, 1912, the Hoosac Tunnel on the Fitchburg Railroad, with an installation costing over a million dollars. The tunnel-line on the Michigan Central Railroad under the Detroit River is operated electrically, as is also the Connaught tunnel on the Canadian Pacific Railway.

These are but a few instances of the many substitutions of electricity on roads with a heavy freight-traffic. In 1912, the Butte, Anaconda and Pacific Railway, a line of 26 miles in the Rocky Mountain region, was electrified, with branches serving copper mines with a trackage of 36 miles. The Chicago, Milwaukee and St. Paul Railway Company has electrified a portion of its main line to the Pacific Coast for 440 miles, covering the summit over the Rocky Mountains. In both of these instances, the moving cause for electrification has been the difficulty of economic operation by steam in a mountainous region, with poor and expensive coal and with water strongly impregnated with mineral salts, as compared with electric traction in proximity to cheap and ample supplies of electric current generated by water-power. For coal-traffic only, the Norfolk and Western Railway Company has recently electrified 95 miles of track in the Pocahontas coal-fields, including a three-mile tunnel, which it was difficult to operate by steam.[1]

Originating in street-railway lines, many electric systems have been developed for suburban and interurban passenger-service and incidentally for light freight-traffic. Interurban lines, principally controlled by the New York, New Haven and Hartford Railway Company, cover the greater part of Massachusetts, Rhode Island and Connecticut, with track-mileage of 1016 miles, and one may travel by trolley-lines from Boston to New York. There is a similar connection of interurban lines in the Middle States, with track-mileage of 3478 miles, including extensions to Washington, D. C.

On April 5, 1909, an electric road was opened from Pullman, a Chicago suburb, to South Bend, Indiana, 76 miles. This road is the western sec-

[1] See Chapter III, page 84.

tion of connecting trolley-lines, extending for 360 miles to Cleveland. Since that date, there has been a remarkable development of interurban service, assuming more of the character of trunk-line passenger-service, in the region between the Ohio River, the Great Lakes, and the Mississippi, with 6768 miles of trackage. The Ohio Electric Railway Company operates a line from Toledo virtually into Cincinnati, crossed at Dayton by another division from Zanesville to Indianapolis, where it connects with other lines in Indiana that cover that State. Including branches, this company has 548 miles of line. The Western Ohio Railway Company operates a line from Piqua to Toledo and a branch to Cleveland, also other branch lines; it has a total mileage of 289 miles. The Illinois Traction System, extending from East St. Louis to Peoria with a branch to Danville, where it connects with lines in Indiana, has a mileage of 297 miles and operates a sleeping-car line between St. Louis, Springfield and Peoria.

On the Pacific Coast, there is an interurban track-mileage of 2685 miles, of which 1936 miles is in California. The Pacific Electric Railway System, for both passengers and freight, centers in Los Angeles with line-mileage of 609 miles and 1286 of track, of which 12 miles is four-track and 1057 is double-track, with revenue, in 1914, of $9,500,000. At San Francisco, besides the suburban lines of the Southern Pacific Railway Company, there is the extensive suburban system of the Northwestern Pacific Railway Company; and from Portland, Oregon, there radiates a track-mileage of 770 miles.[1]

Electric traction for cross-country freight-haulage was inaugurated in 1907 on a new line of 164 miles, the Spokane and Inland Empire Railway. The Oakland, Antioch and Eastern Railway Company, between Oakland and Sacramento, 91 miles, uses electric tractors for freight-service and interchanges freight-cars with steam-roads. At Sacramento it connects with an interurban system in the Sacramento valley with nearly 250 miles of line. The line of this road passes through the Cascade Range by a tunnel through solid rock, 3458 feet in length. An example of the complete operation, electrically, of an interurban road for the interchange of passenger and freight traffic with steam-roads, is that of the line from Albany to Hudson, 32 miles.

There are no official statistics since 1912 of the actual mileage of electric lines in this country. In that year, the track-mileage was given as follows:

Urban lines	23,000 miles
Interurban lines	15,333 miles
Total	38,333 miles

Time-tables of electric roads are given in the Official Railway Guide for August, 1915, operating in the following regions:

[1] Most of these statistics are based on the United States Commerce Report on Electric Railways, 1912.

West of the New England States, north of the Potomac and Ohio Rivers and

East of the Mississippi	22 lines, 1865 miles
West of the Mississippi	22 lines, 1989 miles
South of the Potomac and Ohio	1 line, 126 miles
Total	45 lines, 3980 miles[1]

The commercial use of electric-railway traction abroad was introduced from this country, and the substitution of electric tractors for steam-locomotives followed upon the extension of the Paris & Orleans Railway into its new terminal in Paris, on the Quai d'Orsay, in 1901. Complete substitution of electricity for steam was subsequently effected on the line from Paris to Versailles. After experimenting with electric traction for five years, it was only in 1906 that it was generally applied on the underground systems in London. The most extensive substitution of electricity for steam in Europe is on the suburban lines of the London, Brighton and South Coast Railway which, when completed, will cover 173 miles of track. The London and Southwestern Railway Company has also electrified its suburban lines. Some of the other companies have prepared for electric operation of their suburban traffic, and, within a few years, steam-locomotion will be entirely eliminated from the Metropolitan Zone. With this exception, no important electrification of steam-railways has been undertaken in Great Britain.

On the Continent, the great suburban traffic of Paris is now conducted by electric traction on the motor-car plan, in connection with its urban underground-railway system. Since 1902, the same course has been tentatively pursued with passenger-traffic in and around Berlin; also at Hamburg, since 1907. The substitution of electricity for steam, in main-line traffic, was undertaken experimentally in Germany in 1909, upon a sixteen-mile section of the Magdeburg-Leipsic line. Other experimental service is in progress in Silesia, but, with the exception of a few short local lines on the motor-car plan, there is as yet no extended application of electricity to general railway operation either in Germany or in Austro-Hungary.

The proximity to water-power has led to the use of electric traction in the Alpine region of Italy and on some French lines in the Pyrenees; and the main line to Milan is operated electrically from San Pier d'Arena, near Genoa, through the five-mile tunnel at Ronco, a distance of twelve miles. The lack of coal-mines and the abundance of water-power has induced the Swiss government to enter upon the electrification of the 1875 miles of the Federal railway system, to be completed in 1928. The line from Berne, through the Loetschberg and Simplon tunnels, is now operated electrically to Iselle, some 80 miles; and the mountain section of the St. Gotthard line from Erstfeld through the great tunnel to Bellinzona, 66 miles, is to be ready for electric service by 1920.[2] Outside of Europe and

[1] For other statistics, see Appendix I, Table II.

[2] The electrically operated track-mileage in Europe in 1908 was 8811 miles.

North America, electric-railway traction is principally confined to city-service, except in Australia, where it is to be substituted for steam on a system of suburban lines owned by the city of Melbourne. In 1913, contracts were made with the General Electric Company for the electrification of 150 miles of line in this system, covering 286 miles of track.

Although the substitution of electricity for steam in railway operation has passed from the stage of theoretical discussion to its practical application in certain limited fields, there still remain unsolved important problems affecting its relative economy; while the financial issues involved are far more serious. Much more extensive experience is yet required in the observation of results, and in the perfection of devices and methods, to determine satisfactorily the extent to which this fundamental change in the source of tractive power should be applied in railway operation.

Apart from its electrical equipment, a railroad cannot be operated electrically as it was previously operated by steam. Tracks, yards, terminals, stations, signaling apparatus and telegraph lines must be changed. Special rolling-stock and additional real-estate must be acquired. There is also to be added the cost of power-stations, cables, substations, conductors and feeders, and alterations, estimated at $50,000 per mile even under such favorable conditions as prevail in Switzerland. So that, taking all these items into account, the existing capitalization of our railway system would be more than doubled, were it totally electrified.

The cost of installation of 22½ miles of line west of Stamford has been as great as the original cost of construction of the New Haven line from New Haven to the Bronx, and it was estimated that $30,000,000 would be required for complete electric service from Stamford to New Haven, 36 miles. The electrification of the Pennsylvania railroad line from Broad Street Station, Philadelphia, to Paoli, a distance of 20 miles, with 93 miles of track, cost $3,500,000, and that of an adjoining section of 12 miles to Chestnut Hill is to cost $1,000,000 more, or an average cost of $144,000 per mile for the whole installation. This is not a complete substitution for steam, but merely a trolley-system in the commuting-zone; nor does the expenditure include the cost of power-plant, as the current is obtained from a commercial company. The cost of electrifying the thirty-eight steam railroads within eight miles of the City Hall of Chicago, and covering 3,476 miles of track, was estimated at $178,000,000, but the extension of electric traction beyond that zone, which would be required to meet operating conditions, would increase the total cost to $274,000,000.

With the experience acquired on the New Haven lines, the opinion has been expressed that, "under general conditions, it is improbable that the direct saving resulting from the substitution of electric traction will justify the additional investment for electrifying steam-roads."[1] It is quite a

[1] "Electrification, N. Y., N. H. & H. R. R.," E. H. McHenry, Vice President, Bulletin International Railway Congress, November, 1907, p. 1154.

different matter from the construction of a new line. A great amount of already invested capital must be sacrificed. The transition-stage is expensive and difficult. It affects lighting and heating, telegraph and telephone service, signaling and track maintenance, for which both temporary and permanent provision must be made. The simultaneous maintenance of steam and electric service requires the expenses incident to both, without the full economy of either. To secure the fullest economy the new service must be extended over the whole length of the existing operating district for passenger and freight trains. The concurrent use of steam and of electric traction on the same track has been found to diminish the efficiency of each when used separately. Consideration must be given to the continuing obsolescence of electric equipment due to advance in the art of electric traction; and the "scrapping" of over 63,000 locomotives, representing an investment of not less than $1,500,000,000, will not be seriously entertained under any consideration now conceivable.[1]

The substitution of electric traction for steam has been influenced, so far, more by considerations of social efficiency than of economic efficiency. It has occurred where steam and smoke have become a nuisance in the entrances to large cities and, where so introduced, it has been availed of for passenger traffic between such cities and their suburbs. Gradually the benefits of frequent communication, and of stops at short intervals, have been conferred by electric traction upon thickly populated regions between large cities and incidentally some light freight-traffic has been developed, but, as yet, there has been no electric-railroad construction especially intended for trunk-line freight and passenger traffic. Indeed, the only important instances of such construction for heavy freight-traffic have been upon steam-roads operating where coal was either dear or inferior, or the water impregnated with mineral salts, and where cheap and abundant water-power was available for generating electric current.

The extension of electric-railway operation will therefore necessarily be independent of the existing system of steam-railroads. It can no longer intrude upon the public highways, but must occupy a separate right-of-way at a higher cost per mile than that of the steam-railroads already built. While, to some extent, the earthwork may be of proportionately less magnitude, the track-superstructure is even more expensive. The multiple-unit motor-car is only applicable to light traffic. Trunk-lines can only be operated with electric tractors that are far more costly than locomotives and, their weight being quite as great, there can be no saving in bridges, viaducts and other substructures. Though, under favoring conditions, electric railways have diminished the profits of steam-lines with which they were in competition, their own operating expenses are increasing with the renewals rendered necessary by lapse of time, and

[1] For further discussion of this question see "Problems in Railway Regulation," pp. 286, 294.

their fixed charges are also increasing with additional bonded indebtedness. With the improvement of public highways and the construction of road motor-cars, the "jitney" has appeared as a rival to trolley-lines, and, should its present desultory competition be developed under stronger organization, it may become a serious factor in diminishing the net earnings of suburban electric lines.

It is finally to be recognized that after more than ten years of experimental practice on an extensive scale by a number of important corporations, electric traction has superseded steam on less than 700 miles out of the 254,000 miles in the railway system of the United States. Taking all these matters into consideration, there need be no apprehension of steam being replaced by electric traction to such an extent as to affect the existing capitalization of our steam-railroad system.

Departments of Railway Service

The plant and the personnel of a railroad organization are more immediately devoted to the production, distribution and application of a primary source of power for tractive purposes. On this foundation rests the efficient organization of railway service. The sources of tractive power and its distribution by self-propelled tractors are controlled in the Motive Power Department. The construction and maintenance of the vehicles used in transportation are cared for in the Rolling-Stock Department. It is the office of the Transportation Department to apply these tractors and vehicles to the movement of Traffic. The maintenance of the permanent way and track has brought into the railway service, the Roadway Department, corresponding to a similar organization developed by the former turnpike-service. The substitution of steam for animal power, as a means of traction, was only made commercially successful by the adaptation of the flanged wheel to the iron rail. This led to the control of the tractors, the vehicles and the roadway under a common authority.

The physical environment primarily influences the method of railway operation under every aspect, as is indicated by the similarity of organization which generally prevails. For the division of railway service into operating departments is due to the fundamental distinction between the instrumentalities by which that service is performed. The service in each department is directly affected by the physical environment, since that environment controls the horizontal and vertical alignment of the highway, the design of the tractors and vehicles, the character of the traffic and the conditions of the train-service. All of these instrumentalities are coordinated through the General Management, which is so intimately involved in the entire field of operation that its relation to the several departments into which that field is divided, may be likened to that of the brain to the human organism.

The human or social environment may be separated into that which is political and that which is commercial. The political environment affects the administrative organization; for instance, as to how far that organization may be directly or indirectly controlled either by the State or by capitalists. The political environment may also seriously influence operating efficiency by legislation concerning the scale of wages, the terms and conditions of employment, the conduct of the postal service and other matters relating directly to railway operation. The commercial environment directly affects the compensation for the service rendered in the transportation of persons and things, as also the terms and conditions of that service. It also indirectly affects the cost of operation in the prices of materials and supplies, and in the cost of living. The more immediate relations of railway service to its commercial environment are maintained through that branch of its organization which, in the United States, is known as the Traffic Department. Its relations with its financial and political environment are maintained through its administrative organization. These several aspects of its social environment may be provisionally ignored in a discussion of the efficiency of railway operation, pure and simple, and attention confined to its physical environment and to those operations which relate directly to transportation of persons and things by rail.

Railway efficiency, or the intelligent adaptation of means to ends as affecting railway operation, may, therefore, be considered under several aspects.

I. As Technical Efficiency, or the adequate application of the reaction of Energy upon Matter, as the means to transportation by rail.

II. As Economic Efficiency, or the utilization of tractive power in overcoming train-resistance with the least possible misdirection of Energy or waste of Matter.

III. As Social Efficiency, or the performance of a public service with an assurance of safety, dispatch and convenience to the communities to which the service is rendered.

Technical efficiency relates more directly to the mechanical requirements of railway service. Economic efficiency represents the relative cost of the service performed, while social efficiency represents the relative value of the service which is rendered to communities and to their individual constituents, without special reference to economic efficiency. Economic efficiency in the performance of a service adds nothing to the gross revenue from rendering that service; nor does it wholly diminish the cost of performance, which is largely dependent upon the physical and social environment in which the service is performed. Indirectly, however, by increasing production with the same or diminished expenditure of energy, economic efficiency does diminish the cost of performance by extending the total cost over a larger volume of production, and thereby proportionately lowering the cost-unit with a corresponding increase in net revenue from the same expenditure. Therefore, the benefit derived from saving, through increased economic efficiency, should be considered as a percentage of the net revenue and not of the gross revenue from the service performed.

Economic efficiency directly depends upon technical efficiency as developed in the departments of a railway organization that are devoted to the design, construction and maintenance of the motive power, the rolling-stock and the roadway, which are the material elements of transportation by rail. Efficiency in each of these departments will now be separately considered.

CHAPTER III

MOTIVE POWER

Locomotive Efficiency

The operation of a railroad is primarily undertaken as the means for transporting persons and things from one place to another by land-carriage; mechanical energy being substituted for vital energy as the motive power. That which is sold is traction, and the basis of traction is the output of mechanical power created for that purpose. Thus we may regard railway service as a product in all respects similar to the output of steam-power, water-power or electric power, generated for any other purpose.

In ordinary railway operation, steam as a motive force is applied through the locomotive as a tractor. It may be applied through many separate tractors though not all of similar design. Even the locomotives in use on any one railroad are diverse in this respect, and, if we are seeking for a basis of efficiency in the output of tractive force on a particular railroad, we should endeavor first to ascertain what its motive power ought to do as a whole, and then what it really does in fact. In other words, there should be a comparison of Duty and Service; Duty being that which should result, if the entire motive power were worked up to its theoretical capacity, and Service that which, in practice, results from the application of the power to the purposes for which it is intended. Duty, therefore, is that which ought to be done. Service that which is actually done. Duty is efficiency at one hundred per cent. Service is the percentage of efficiency virtually attained.

Technically, efficiency is the ratio which the useful work performed in any operation bears to the energy expended in doing it. This ratio, as theoretically estimated, may be termed Duty; and the ratio, as actually ascertained in any specific instance, may be termed Service. The efficiency of any particular locomotive, as a tractor, may be estimated by the percentage of Service to Duty expressed in convenient units of measurement; say in tractive pounds, as indicated by the dynamometer at the locomotive draw-bar, or the draw-bar pull. From such data, the total tractive power of the entire locomotive-equipment of a railway may be ascertained, and, consequently, the estimated and the actual potency of that railway as a means of transportation.

This proposition is illustrated by a statement recently made by the President of the Pennsylvania Railroad Company to the Interstate Commerce Commission. In the period of ten years, ending June, 1913, the equipment of that company in locomotives had increased 45 per cent., and their tractive power had increased 80 per cent., or 99,521,170 tractive pounds. Here is an example of the increased potential efficiency of a railway as a means of transportation. It is also a practical recognition of the fact that the primary purpose in railway operation is the production of tractive power.

The tractive power of the locomotive may be resolved into its several elements, and the merits or demerits of any locomotive, with reference to either of these elements or factors in the production of motive power, may be intelligently investigated and accurately ascertained. The field of research is wide, for the independent plants are numerous. The opportunity for fruitful results would be far greater if more attention were given to ascertaining the output of a railroad's tractive power, obtained from the locomotive-equipment, in general, instead of confining the investigation only to locomotives of recent design. If this course were pursued, many locomotives would be found so wasteful of energy that it would be more profitable to discard them than to continue them in service.

The economic value of a locomotive depends upon its efficiency in three respects: first, as a steam-generator; second, as a mechanism for the conversion of energy into mechanical power; and third, as a mobile tractor, through its adhesion to the rails. By the transformation of water from a liquid to a gas, energy is developed from heat in the generator — the boiler. This energy is then converted into mechanical power in the steam-cylinder — the motor, from which it is transmitted for traction through the adhesion of the driving wheels. The combination of these three functions in a self-contained mechanism — the locomotive — is the basis of railway transportation, which is the dominant factor in the material prosperity of every country into which it has been introduced.

Of the three requisites here described, the efficiency of a locomotive as a steam-generator is ascertained by the relation of the number of heat-units required to evaporate a certain quantity of water in a given time. Its efficiency as a mechanism is virtually independent of its efficiency as a steam-generator, though that there is some relation between them may be gathered from discussions as to the relative merits of superheating steam and of its expansion in simple or in compound engines. The third element of efficiency in a locomotive, considered as a mobile tractor, is determined by the relation of its development of power to its adhesive weight; that is, by its wheel-arrangement. The economic value of a locomotive depends not only upon its efficiency as to each of these requisites, but also as to their interrelation. That is, whether the steaming-capacity of its boiler be duly proportioned to the expansive capacity of its engines, and likewise whether this capacity be duly proportioned to its available adhesive weight. It is the proper relation of these fundamental elements in a locomotive which constitutes efficient design.

Chief among these elements is the agency of combustion in the generation of steam; and here there are two factors of efficiency, — the evaporative capacity of the boiler, and the calorific value of the fuel. Remarkable economy in fuel-consumption has been attained in stationary plants, but the same percentage of efficiency is not to be expected from the locomotive, because of the different conditions under which is it operated. The opportunities for economy are far greater when the conversion of heat as motive force is accomplished at a central station, than when it is distributed among a number of independent mobile tractors. For, at a central station, ample space may be provided for the installation of appliances for mechanical stoking, for improved draft, for feed-water heating and for making further available the wastage of heat from accessory apparatus.

The essential features of the locomotive as a steam-generator are the multi-tubular boiler and the forced draft by exhaust-steam; these were, indeed, the characteristic elements of the first successful locomotive, — George Stephenson's "Rocket."[1] From that day forward, there has been no marked advance, as to design, until the advent of recent devices for superheating steam, which are still in somewhat of an experimental stage. The violent combustion in the fire-box, and the velocity with which the products of that combustion are transmitted through the tubes, in consequence of the forced draft, result in their delivery at the smoke-box still with a very high temperature, and with a corresponding waste of heat-energy, under the operation of Carnot's Principle.[2] For these reasons, the locomotive-boiler is necessarily a wasteful consumer of fuel.

The evaporative capacity of the boiler is not the same at the fire-box as at the tubes. In the fire-box, the effect is produced by radiant heat, directly from the fuel; in the tubes, by convection from the heated gases rushing through them to the smoke-box. The ratio of total heating-surface to grate-area is also an important matter. It should not exceed eighty times the grate-area, and more economical results are obtained at sixty-five times the grate-area. Even with ample grate-area and fire-box heating-surface, the grates and ash-pan should be carefully designed with reference to the quality of coal and the required rate of fuel-consumption. It is assumed that 2½ square feet of heating-area will produce one indicated horse-power when the grate is properly proportioned to the

[1] See Appendix II, Table XIX.

[2] Carnot's Principle. Heat-efficiency is fixed solely by the temperature of the bodies between which, in the last resort, the transfer of heat is effected; that is, in a steam-engine, by the difference between the temperature of the exhaust-steam and that of the atmosphere. The less the absolute temperature of the atmosphere and the less relative difference between it and the temperature of the exhaust-steam, the more efficient is the locomotive as a heat-engine.

heating-surface, and with regard also to the quality of fuel. With a fair quality of bituminous coal, 120 pounds per square foot of grate-area per hour is considered the maximum rate for economical evaporation, and with anthracite, 55 to 70 pounds per square foot, according to its quality.[1]

With bituminous coal, the front end of the fire-box should be bricked off as a combustion-chamber; for a large percentage of bituminous coal burns above the grate as gas and the short time allowed for discharging and refilling the gases in the fire-box (about six times a second), is insufficient for the perfect combustion of each particle; therefore, the gases must be mixed, either by an arch or a baffle, which forces them through a restricted area not less than the flue-area. The baffle and the combustion-chamber not only aid combustion but also increase the radiating-surface, with corresponding increase in fire-box evaporation and in lowering the temperature of the escaping gases. Combustion-chambers lengthen the flame-travel, but the arch, especially on supporting water-tubes, doubles the average length of flame-travel and also possesses the more important advantage of a mechanical admixture of the gases, while the supporting-tubes expedite the circulation of the water; thus insuring a higher rate of heat-transfer. Thirty years ago, brick arches were rarely used, except experimentally, and, at one time, virtually discarded. This device has since been so much improved that, in 1914, it was estimated that there were 30,000 locomotives so equipped in the United States and in Canada.

The length of the barrel of the boiler, and therefore of the tubes, is determined more by the wheel-arrangement than by thermal conditions. Fifteen years ago, tubes were usually from 12 to 14 feet in length, while lengths from 20 to 24 feet are now in use. The ratio of tube heating-surface has accordingly increased from 8 to 12 per cent., and, in larger locomotives, to 20 per cent. In the longer tubes, the heat is better utilized, because the range of temperature is greater between the furnace and the stack. The evaporative value of the tubes varies also with their diameter and with the manner in which they are spaced.

The effect of fierce combustion is unsatisfactory, as much unburnt coal is drawn through the tubes and thrown out of the stack by the violent draft. The chief advantage of the present draft-arrangement is in its simplicity, — free from complicated parts and requiring only minor adjustments. As all other systems of forced draft have been found impracticable, further improvement is probably to be sought in a less violent

[1] English locomotives use a good quality of coal and have grate-area of about 23 square feet. German locomotives of the same size have about 32 square feet or about 12½ per cent. more, being adapted to a lower grade of fuel. The large French locomotives have from 35 to 40 square feet of grate-area; or, in proportion to weight, about the same as in British practice. American locomotives have proportionately more grate-area than British or French; 60 to 70 square feet being usual for the Mikado type, and 88 square feet for the Santa Fé type. — Bulletin of International Railway Congress.

draft, mechanically produced. Centrifugal fans as now designed cannot be constructed of sufficient capacity, within the necessary limitations of space for locomotive-use. Promising results have, however, been obtained from blowers of the turbine-type, but some other design than the ordinary exhaust-nozzle must be adopted, if it is intended to use powdered coal as locomotive-fuel.

The necessity for the rapid production of steam from a relatively small volume of water is well provided for in the locomotive's multi-tubular boiler, but its steaming-efficiency has now about reached the limit permitted by the restrictions due to the gauge of the track and to its supporting-power. Within the limits thus placed upon additional grate-area and increased heating-surface, the locomotive-boiler may be considered an efficient steam-generator, though not an economical one.

Locomotive-boilers were originally constructed in a dome-shape over the fire-box. This form was superseded by the "wagon-top" over the fire-box, with the entrance to the steam-pipe in a separate dome, or rather a cylindrical chamber, attached to the barrel of the boiler. Drier steam could there be obtained than over the fire-box, where the water was in more violent ebullition. The "wagon-top" also affords opportunity for a better method for attaching to the boiler-shell the stays by which the crown-sheet is braced. As boilers were designed of larger dimensions, the "wagon top" was extended farther forward. The "Belpaire" type of boiler, with a square top over the fire-box, has also been introduced from France, with the fire-box attached to the boiler-shell by radial stays. On roads using anthracite coal, a wide and shallow form of fire-box, known as the "Wooten" fire-box, is in use for burning anthracite culm.

It is of interest to note some of the results obtained in tests to ascertain the ratio of the evaporative capacity and fuel-consumption of locomotives to the tractive power delivered at the draw-bar. In the Pennsylvania Railroad tests at the St. Louis Exposition, in 1904, there was obtained equivalent evaporation, from and at 212 degrees, of 16.4 pounds of water per square foot of heating-surface per hour; this being the evaporative capacity of the boiler when forced. Under lower pressure the evaporation per pound of coal was 10 to 12 pounds of water, which declined to two-thirds of these values when the boiler was forced. These figures show the existence of an economic balance between fuel-consumption and efficient evaporation. The ratio of evaporation in ordinary stationary engines is usually from 4 to 7 pounds per square foot of heating-surface per hour, but with proportionately lower fuel-consumption. This result is, however, obtained by the intervention of heat-saving appliances which are not available on a locomotive.

In recent practical tests at Altoona, the best record with dry coal was 1.8 pounds of coal per indicated horse-power per hour, and the best performance with dry steam was 14.6 pounds of steam per indicated horse-power per hour. The maximum equivalent evaporation, from and at 212 degrees, per square foot of heating-surface per hour, was 23.3 pounds. The St. Louis tests showed a minimum steam-consumption of 16.6 pounds of steam per i.h.p. per hour. The lowest figure of fuel-consumption was 2.01 pounds per i.h.p. A reduction of 10 per cent. in fuel and of 12 per cent. in water indicates the development of motive power efficiency in ten years in the best contemporary practice. In the Altoona tests, the best fuel-performance was obtained from a locomotive making 320 revolutions per minute and developing 1245.1 i. h. p. The best water-rate was by another locomotive at 320 revolutions per minute, developing 2033.1 i.h.p. On an average, in simple engines with 700 to 1000 feet of piston-speed per minute, one horse-power can be obtained from 27 pounds of saturated steam, or from 23½ pounds in compound engines. With superheated steam, the same unit of power can be obtained from 20.8 pounds in simple engines, and from 19.7 pounds in compound engines, including steam for auxiliary purposes.

Attempts to economize in fuel by feed-water heating have not been successful. The experimental saving of about ten per cent. has been obtained by appliances which complicate the operation of the locomotive in other respects. Still, an open feed-water heater under the boiler may yet be found practicable, using exhaust-steam from the air-pumps and boiler-feed, and partly from the main exhaust.

Feed-water containing a considerable volume of solid matter in suspension, or salts of lime or of magnesia in solution, may seriously diminish the steaming-efficiency and endurance of boilers, by causing deposits on the boiler-sheets and tubes. Under such conditions, the feed-water should be purified before it is used. The solid matter may be removed by filtration. Where the water is very alkaline, say as much as 300 parts to the million, it has been found necessary to install expensive apparatus for its purification. This may be accomplished either with soda-ash, quick-lime or gypsum as a reagent, according to the chemical nature of the impurities.[1] Water containing organic acids is also objectionable. A road in Florida that obtained its supply from surface-water collected in ponds, was much troubled with leaky tubes. This was attributed to the action of organic acids derived from the roots of the dwarf-palmetto, which grows there in abundance. The acid acted upon the crystals of free carbon in the iron tubes, pitting them in minute holes, and brass tubes were therefore substituted.

Any set of combustion data lacks completeness in so far as it does not give the calorific value of the fuel consumed, since that value varies from 8000 British thermal units per pound, in slack or culm, to 16,200 B. T. U.

[1] The effect of a water-purification plant was shown on a division of the Missouri Pacific Railroad by a comparative statement of 166 locomotive-failures from boiler-leaks in January, 1905, reduced to 10 in January, 1906. — "Economics of Railway Operation," Byers, 1908.

in cannel coal. For, at last, all computations of the effect of heat applied as a mode of motion must be measured in heat-units to be of service for purposes of comparison. With such a basis of the comparative values of fuel, the efficiency of different boilers may be measured as to their evaporative capacity in pounds of water in units of time, with an equivalent number of heat-units, and their relative economy as steam-generators may thus be accurately ascertained before proceeding to the valuation of the mechanism of the locomotive and of the conversion of steam as a motive force into tractive power.[1]

Efficiency in heat-units is equivalent to the number of foot-pounds of work per pound of steam or, conversely, to the number of pounds of steam per horse-power per hour. The heat required to produce one pound of saturated steam from water at zero Centigrade, or 32° Fahrenheit, is about 650 times the amount of heat required to raise the temperature of water one degree Centigrade. The British thermal unit (B. T. U.) represents the energy of heat absorbed in raising the temperature of one pound of water one degree Fahrenheit, and is equivalent to the power required to raise 777 pounds' weight one foot high at latitude 45°, sea level. Similarly, the metrical calorie, or kilocalorie, represents the heat-energy absorbed in raising one kilogramme of water one degree Centigrade, and is equivalent to the power required to raise 426.3 kilogrammes one meter in height, or a kilogramme-calorie. There is a lesser calorie, or gramme-calorie, which represents heat energy of 426.3 grammes.[2]

Where a reliable supply of fuel-oil can be obtained at suitable prices, it is being substituted for coal, with great advantage as to furnace-deterioration and with the reduction to a minimum of the strain upon the physical energy of the fireman. One and a quarter tons of oil are estimated to have the economic value of two tons of good coal, but care must be taken to separate the water that is sometimes associated with the oil. With many oil-burners, the water-supply and oil-supply are carried in a tank-car instead of the ordinary tender, and the cab for the engine-driver and the fireman is placed at the front end of the locomotive. In 1908, out of 56,867 locomotives in service, there were 2,354 oil-burners; in 1914, out of 64,760 locomotives, 4,140 were oil-burners. In six years, there had been an increase of 1,786 oil-burners, or 76 per cent. The consumption of fuel-oil increased from 30,000,000 barrels, in 1914, to 37,000,000 barrels, in 1915, or 23 per cent. It is now in use upon forty railroads in this country, and the increased consumption is affecting the value of the official statistics of coal-consumption in its ratio to ton-mile performance.

[1] See Appendix II, Table XX.

[2] One B. T. U. = 0.252 kilocalorie.
One kilocalorie = 3.968 B. T. U.
One B. T. U. per cubic foot = 0.1123 kilocalorie per cubic meter.
One kilogrammeter = 7.233 foot-pounds.
777 foot-pounds = 107.424 kilogrammeters.

On the Florida East Coast Railway, twenty-five locomotives have been recently converted into oil-burners. The fire-pans are round-bottomed and slope from back to front; so that any accumulation of oil in the pan may drain out at the forward end, without danger from explosion. A course of brick is set on edge along the sides of the pan, to protect the lower portions of the side-sheets from the intense heat, and to seal the pan at the point of its attachment to the mud-ring. Air is admitted through a damper at the front wall of the fire-pan, and through a second damper controlling the supply through the flash-hole, which is placed about two-thirds of the distance from the burner back to the rear of the pan. A four-inch length of tubing is inserted in each of the perforations in the front wall of the fire-pan, covered by the first damper. Air-supply is received at this point in firing-up. After steam has been raised, this damper may be partially closed and further air for combustion received through the second damper, which is manipulated by a notched lever in the floor of the cab. The average mileage per ton of coal was 18.11 miles, and, with coal at $3.04 per ton, the cost per mile run was $0.167128. During the same period, with oil at $0.017 per gallon, the mileage averaged .124 mile per gallon at a cost per mile run of $0.137467.[1]

More than one-fifth of the total coal-production of the United States is consumed by locomotives. In 1906, this consumption amounted to 90,000,000 tons, valued at $170,500,000, and was accounted for as follows:

Utilized as motive force	41,000,000 tons
Unutilized as motive force	31,000,000 tons
Consumed in incidental service	18,000,000 tons

The incidental consumption of fuel is in starting fires and in keeping up steam while the locomotive is standing, as well as the loss through blowing off at the safety-valve and from coal dropped in the ash-pit at the end of a run. The unutilized expenditure of heat-energy in train-service can be very little further prevented by economizing devices; but the incidental consumption of fuel might be considerably reduced, if proper attention were given to it.

The use of pulverized coal as fuel in the manufacture of cement and in metallurgical processes, has induced experimental tests of its value as locomotive-fuel. A report by a committee of the Railway Fuel Association summarizes its advantages for this purpose, as follows:

1. Absence of smoke, sparks and cinders.
2. Maintenance of maximum boiler-pressure within an average variation of three pounds.
3. Increase of 7½ to 15 per cent. in boiler-efficiency.
4. Saving of 15 to 30 per cent. in fuel of equivalent value.
5. Enlarged nozzle-area.

[1] Journal Am. Soc. Mechanical Engineers, August, 1916, p. 666.

6. Elimination of ash-pit delays and expenses, with reduction in time required for firing-up.

7. Maintenance of a relatively high degree of superheated steam.

8. No accumulation of cinders, soot or ashes.

9. No overheating of fire-box.

10. Elimination of arduous labor in firing, and in building, cleaning and dumping fires.

11. Avoidance of expense in providing various sizes and kinds of fuel.

12. Elimination of front-end and ash-pan inspection, and the use of special tools and appliances for building fires and for stoking and cleaning them.[1]

If the nuisance caused by smoke and cinders can be prevented by the use of pulverized coal in connection with a hot-air blast, its use within city limits might be a preferable alternative to expensive electrification.

Coal Handling and Mechanical Stoking

After human efficiency has apparently been exhausted in the development of mechanical efficiency in the locomotive as a steam-generator and as a mechanism, its practical efficiency as a tractor depends upon human efficiency of another kind, — upon the vital energy and the skill of the fireman. The vital energy expended by him in this service is in striking contrast with the demand upon the muscular power of his companion at the throttle-lever; for the engine-driver expends but little energy in controlling the speed of the locomotive. The service that he performs is like that of the marine pilot, except that the course of the train is directed by the flanged wheels and the rails. His attention is given mainly to maintaining the required speed, conforming to the train-schedule and observing the indications of the signaling apparatus. In fact, the engine-driver is not essentially connected with the Motive Power Department, but rather with the train-service. On the contrary, the vital energy of the fireman is heavily drawn upon in the production of tractive power; a task that requires skill, as well as muscular strength and physical endurance.

Skill in handling the scoop decreases the demand upon the fireman's vital energy, and training in the disposition of fuel in the fire-box decreases the ratio of fuel-consumption to water-evaporation. Instruction in both of these matters has been undertaken by some railroad managements, but, as a general thing, they have not received the attention that their importance requires. The value of such instruction may be measured by a statement recently made by Mr. E. H. Coapman, Vice-President of the Southern Railway in charge of operation, that in six years the consumption of coal on that line had been reduced 31 per cent. He accounted for this

[1] "The Use of Pulverized Coal as a Fuel." Joseph Harrington. Journal Am. Soc. Mechanical Engineers, October, 1916. See also Appendix II, Table XXI.

remarkable result by the application of scientific and practical tests as to the quality of coal and by the use of superheaters, but he laid emphasis upon having practical men to teach the fireman, and by recording "the number of scoops of coal that each fireman throws into the fire-box for every hundred miles he runs." It is interesting to note the manner in which this was accomplished. After a careful adjustment on each locomotive of the draft-appliances, the valve-motion and the cylinder-packing, and of the admission of air through the grates, the fireman was trained in the reduction of useless consumption of fuel at terminals. The fire was either drawn or banked, according to the time that the engine was standing. When banked, the fire was moved forward on the grates, so that the admission of air would check combustion without cooling the flue-sheet. The furnace-door was operated by compressed air, controlled by a treadle-lever. The opening was set at three seconds, which allowed time for firing a single scoop of coal, averaging 14½ pounds. Each movement of the door was recorded by a device attached to it, and the fuel-consumption was thus readily determined at the end of each trip.[1]

The demand upon the muscular power and the endurance of the fireman has been much increased by the introduction of more powerful locomotives. For every additional horse-power there has been a large increase in fuel-consumption, notwithstanding the improvement in mechanical efficiency. The physical efficiency of the fireman therefore virtually determines the practical efficiency of the locomotive. On locomotives of the larger classes, this task has approached the limit of human endurance; and a great amount of ingenuity is now directed to lighten the fireman's labor by the intervention of mechanical stoking-apparatus.

It is stated as a well-known fact that there is a difference of twenty-five to fifty per cent. in the amount of coal burned by different firemen in performing the same work, and that few locomotives of 50,000 pounds' tractive power can be worked to their full capacity by shovel-firing. In a random test of ten classes of heavy freight-locomotives, built in the last three years, it was found that, to deliver their full power, from 4900 to 8000 pounds of good coal were required per hour; while they were actually getting from 4500 to 5000 pounds only, and hauling trains of corresponding tonnage. As a consequence, all the locomotives of the same class on the

[1] On the Chicago, Rock Island & Pacific Railway, during the year ending June 30, 1915, in freight-service there was an average consumption of 16 scoops of coal per engine-mile; in passenger-service, 7.4 scoops per engine-mile, and 9 scoops per switch-engine mile. A reduction of only one scoop of coal per freight-engine mile and one-half a scoop per passenger- and switch-engine mile would result in the following annual saving:

Freight-service, 131,022 tons	$294,799.50
Passenger-service, 67,496 tons	151,864.75
Switch-service, 24,045 tons	54,101.25
	$500,765.50

Railway Review, April 1, 1916.

same runs are now rated according to the ability of a fireman of average efficiency.[1]

With a locomotive consuming 4900 pounds of coal per hour, the fireman must handle 80 pounds, or five shovelfuls of 16 pounds each, per minute. At this point, his maximum capacity has been reached. To secure the full power of locomotives consuming fuel at this rate, mechanical efficiency must, therefore, be substituted for physical efficiency.[1]

There seems to be no question as to the practicability of mechanical stokers on heavy locomotives. They have been tested up to a capacity of eight tons per hour, or four times as much as can be expected from shovel-firing. With a superheater, the rating was increased to 5000 tons and, after it was fitted with a stoker, the rating was further increased to 6000 tons. A rivalry followed with the superheated locomotives that were shovel-fired which had the effect of increasing their rating to 5500 tons; so that a single mechanical stoker increased the commercial value, in tonnage-service, of every locomotive on that division. On a division with ten tonnage-trains a day, mechanical stokers effected an increase of 11 per cent. in the tonnage, although the return-movement was largely in empty cars. The saving in wages and in train-supplies amounted to about $100 per month per locomotive. Wherever mechanical firing has been introduced, it has resulted in increased tonnage of from 10 to 20 per cent.; it also assists in burning a cheaper grade of coal with a more uniform rate of consumption. There were in use, in 1915, 301 stokers of the under-feed type and 531 of the over-feed or "scatter" type.[2]

With increasing experience, the stoking apparatus is becoming greatly simplified. It is now constructed of fewer, stronger and heavier parts, with very few moving surfaces. A well-designed stoker should handle coal from the tender in any condition and with a minimum degree of attention. It should not require alteration after having been properly adjusted, and should be controlled from the seat-box, where the fireman can keep a better lookout for signals; and it should make no noise that could be heard while the locomotive is in motion. For the mechanical stoker to be a success, it should be developed as an integral element of the locomotive, and not as an adjunct or afterthought.

Steam Economy

The economic use of the expansive properties of steam is the measure of the efficiency of the locomotive. While economy in fuel-consumption depends upon the design of boilers and of their accessories, the efficiency

[1] Experiments conducted in the Pennsylvania Railroad laboratory have shown the thermal efficiency of a locomotive-boiler to be 73.2 per cent. with experienced firemen, and but 59.7 per cent. with inexperienced men.

Railway Club of Pittsburgh. Jan. 28, 1916.

[2] Proceedings Am. Master Mechanics Association, 1915, p. 35.

of the locomotive, as a mechanism, depends more directly upon the design of its engines. The locomotive, unlike most steam-engines, is operated under widely varying conditions as to power and speed. Its maximum power must often be developed in starting a train. The consumption of steam may then be diminished by utilizing its expansive properties, without impairing the efficiency of the locomotive as a tractor. Its full power, in this respect, is attained when operated at from 700 to 1000 feet of piston-speed per minute.

The design of the locomotive, as a mechanism for the conversion of heat-energy into tractive power, is controlled by the necessity of conforming to these conditions. This result has been attained with high-pressure engines of a simple type, with rapid piston-motion and short stroke proportionately to cylinder-diameter. The rapidity with which the reversal of this motion is accomplished, renders it impracticable to regulate the admission and release of steam by the poppet-valves in use on stationary engines. This difficulty was overcome by the invention of the slide-valve controlled from a driving-axle.

A practical difficulty appeared in the sudden reversal at high speed of the parts of the engine in reciprocal motion. The consequent shock to the pin-connections was obviated by a delicate adjustment of the valve, relatively to the angular position of the crank-pin, that permitted the admission of steam into each end of the cylinder momentarily before the arrival of the piston there, resulting in a compression of the steam. A reaction then followed against the momentum of the moving parts by which the shock to the pin-connections was neutralized. This process, called "cushioning," reduced the liability of the piston's going through the cylinder-head by the breaking of a crank-pin. The conversion of rotary motion from the driving-axle into reciprocal motion of the slide-valve by means of the eccentric, and the adjustment of that eccentric to coördinate the valve-motion in proper relation with the piston-motion, is a striking example of mechanical ingenuity.

A further development of the eccentric-motion was devised in the link-motion, attributed to Robert Stephenson. This ingenious appliance for controlling the admission of steam into the cylinder at different points in the stroke of the piston, made the expansive action of steam available through a wider range than with the half-stroke cut-off, which was long afterward in general use in the United States. The link-motion has therefore been a valuable aid to steam-efficiency, though, for mechanical reasons, it has been largely superseded, on European roads, as well as in this country, by the outside valve-gear, known as the Walschaert type.

The demand for greater tractive power in the locomotive could only be met by increased steaming capacity at higher pressure and by larger cylinders. Longer ports were then required to facilitate the admission and release of steam, and the necessarily wider slide-valves exposed a greater area to steam-pressure. The consequently increased friction between the faces of the valve and of the cylinder-ports brought such an excessive strain upon the valve-gear that, in the larger locomotives, this difficulty had to be obviated by balancing the slide-valve by means of internal steam-pressure, or by the substitution of the piston-valve.

The efficiency of the valve-motion of a locomotive-engine may be illustrated by the example of a locomotive with driving-wheels six feet in diameter, running at a speed of sixty miles an hour. At this speed, the wheels revolve about 280 times a minute, while the motion of each piston is reversed over nine times a second. The valve-motion, which regulates the admission of steam to the cylinder with this frequency, is under a pressure of perhaps 200 pounds to the square inch. From this example, a conception may be formed of the efficiency of a device that combines such delicacy of adjustment under such a strain, and that, too, on a motor whose great momentum subjects the whole mechanism to sudden shocks by the incessant reaction of the flanged wheels and the rails.

In the early British locomotives, the steam-cylinders were inclosed in the smoke-box and connected with cranked driving-axles. This arrangement was retained on European roads long after American builders had transferred the cylinders to the outside of the frames, to make way for the center-bearing truck which characterizes our railway practice. With this change of position, there has been a considerable loss of heat by radiation to the atmosphere, obviated to some extent by jacketing the cylinders; but this loss has been more than compensated by doing away with the cumbrous and unreliable cranked-axle, and by readier access to the moving parts of the machinery. This change has been generally adopted, and the inside-connected simple engine is now a thing of the past.

The Compound Locomotive and Superheating

The successful application, in marine and stationary engines, of the principle of steam-expansion through a series of cylinders, led to its experimental application to the locomotive by the eminent French engineer, Anatole Mallet, in 1876. In its original form, the exhaust-steam from a high-pressure cylinder on one side was expanded into a low-pressure cylinder on the other side, of about double its capacity, through the intervention of a receiver in the smoke-box. In this design (known as the cross-compound engine), in order to start a train, high-pressure steam had to be introduced into the low-pressure cylinder at a reduced pressure. This objectionable feature was obviated, in 1878, by Mr. Webb, of the London & Northwestern Railway, in the three-cylinder compound, composed of two outside high-pressure cylinders expanding into one low-pressure cylinder, placed in the smoke-box and connected with a cranked driving-axle. In 1889, one of these locomotives was introduced on the Pennsylvania Railroad for experimental purposes.

The Baldwin Locomotive Works built cross-compound engines in 1898, and subsequently originated the "Vauclain" four-cylinder compound, with one high-pressure and one low-pressure cylinder, arranged vertically on each side. The mechanical difficulties involved in doubling the connections with the driving-wheels of engines so placed, were ingeniously overcome and, in this design, compound engines met with more favor in the United States. It was further developed in the "balanced" compound, with the two high-pressure cylinders under the smoke-arch and the low-pressure cylinders outside. The inside pistons were connected to crank-axles at 90° with the corresponding crank-pins on the outside engines, thus eliminating counterbalancing. Another variety of the four-cylinder compound was the "tandem" compound, built also by the Baldwin Locomotive Works in 1902, and intended for heavy freight-service, keeping the low-pressure cylinders of larger diameter within the clearance-limits. In this design, the high-pressure cylinders were placed forward of the low-pressure cylinders, with both pistons on the same rod. A steam-chest common to both served also as the intermediate receiver.

The increase of tractive power at one step from 40,000 pounds in the simple engine up to 72,000 pounds, working compound, and even to 86,000 pounds in emergency, was at first severely criticized. Yet to-day there are compound engines working up to 115,000 pounds, and to 138,000 pounds in emergency. Engines have even been designed to give 140,000 pounds' tractive power, compound, and 168,000 pounds in emergency.

The compound locomotive has undoubtedly a superiority over the simple locomotive in handling heavier trains with a relative reduction in fuel and water consumption, and, it is also claimed, with less boiler-repairs, an improvement in riding qualities and the practical elimination of jerks in starting. Yet the compound engine seems to be losing ground in American practice, except as applied in the articulated or Mallet type. The statistical reports of the Interstate Commerce Commission show that, in 1910, there were in use in this country 862 two-cylinder and 1511 four-cylinder compound locomotives. In 1914, there were only 659 two-cylinder and 1333 four-cylinder compound locomotives.[1] This decrease of 203 two-cylinder and of 178 four-cylinder compounds is exclusive of the articulated type, of which there were 775 in use in 1914, all with four-cylinder engines.[2]

The diminution of interest in compound engines is attributed principally to the growing belief in the superior efficiency of working dry steam

[1] See Appendix II, Table VI.

[2] In 1889, there were 689 compound locomotives in use in Europe; in 1892, there were 1858. In 1900, the French companies had adopted the four-cylinder compound engines.

in the simple engine over using saturated steam expansively in the compound engine. Superheating-apparatus was introduced on the German railways, in 1898, by Dr. Wilhelm Schmidt, and was introduced into the United States in 1906. In 1916, there were 16,000 superheated locomotives in use in the United States and Canada and, in 1917, over 21,000 were in service or under construction.

The superheater is estimated to secure an economy of 25 per cent. in fuel, as a direct result of 33 per cent. reduction in the total water-evaporation, per unit of power. Its effect upon fuel-consumption has become recognized, though there are no official statistics as to the extent to which it has been applied. Both in freight and passenger service, there are locomotives developing at least one-third more power than would be possible with simple engines using saturated steam and consuming an equal quantity of fuel. They are also operated at less boiler-pressure than with saturated steam. The economy in superheating seems to be confined principally to locomotives on high-speed trains with few stops, and therefore operated in passenger-service.

In the Schmidt apparatus, superheating is accomplished by circulating saturated steam through looped tubes introduced into certain boiler-tubes, enlarged in diameter, before the steam passes into the steam-chest. But the usual type of fire-tube superheater produces its maximum effect only when it is forced to the limit of boiler-capacity. The material in valves, cylinders and packing, as well as the lubrication, will not withstand superheating above a certain temperature. In other devices, the steam is superheated in the smoke-box.[1]

A serious drawback to the efficiency of the locomotive is due to the back-pressure that follows upon the use of exhaust-steam in the forced draft. Tests upon eighteen different types of locomotives, working under various conditions, showed that for every hundred horse-power used in traction, sixty-six horse-power was wasted through the exhaust. Over

[1] The tendency is to increase the gas-area available for superheat at the expense of the boiler-tubes. Steam is used at a temperature in excess of 750° F. The limit is only fixed by the ability of the exposed machine-parts to withstand the high temperature. Although superheaters were originally applied to heavy locomotives using steam for long periods of run, there is an increasing use of them for switchers. There are now over 1300 locomotives equipped with superheaters. — Geo. L. Bourne, Journal Am. Soc. Mechanical Engineers, September, 1917.

The benefit of the superheater finds its limit when an increase of cut-off halts a further reduction of specific steam-consumption. The speed and pressure at which this takes place depend upon the proportions of the boiler as compared with the cylinders and wheels. The locomotive should be so designed as to provide the boiler with its proper evaporating and superheating surfaces, so that the largest amount of sustained horse-power can be had at the speed at which the locomotive is required to operate under normal conditions.

The large smoke-tubes now used in this country are $5\frac{1}{4}$ and $5\frac{1}{2}$ inches outside diameter, with $1\frac{1}{2}$ inches outside diameter superheater-unit tubes. — R. M. Ostermann, *ibid.*

70 per cent. of this waste was due to the excessive back-pressure necessary to produce the forced draft. Other tests were made in 1914, on a locomotive of the Prairie type, by changes in the front-end arrangement. Assuming the efficiency of the original arrangement at 100 per cent., a draft of six inches' water-pressure was produced at a saving of 34.5 per cent. in back-pressure. Yet this saving of wasted power only increased the total power of the locomotive by five per cent. It reached its maximum efficiency at a speed of 35 miles an hour, developing 1350 indicated horse-power with 190 horse-power of back-pressure. Until some kind of blower can be substituted for exhaust-steam, there seems to be no practical way of eliminating the back-pressure.

Apart from the improvements already noted, the locomotive is still a simple reciprocating steam-engine, varying but little in its essential features wherever operated. But in the application of steam to railroad traction there is a wide variation in the coördination of motive power to tractive effort. That effort is exerted by the leverage of the driving-wheels upon the rails, and it is here that the necessary relation of weight to adhesion is manifested. The differences in practice are due to differences in environment, physically and socially. The ruling-gradients and the character of either passenger or freight traffic control the relative power and weight of the motors, and also the arrangement of the driving-wheels by which that power and weight are made available in the locomotive as a tractor.

Wheel Arrangement and Design

The early English locomotive, as used in colliery service, was little more than a stout wagon. The power from the cylinders, which were placed in the smoke-box, was more conveniently applied only to the back pair of wheels on a cranked axle. As the value of steam-traction for rapid motion became apparent and was applied to passenger-traffic, this pair of wheels was increased in diameter to as much as seven or eight feet; the adhesion being still sufficient to overcome the inertia of the few and light carriages of which a passenger-train was at that time composed.[1] The diameter of the driving-wheels was limited by the necessity for passing the axle under the barrel of the boiler, with clearance for crank-action, at a height not so excessive as to raise the center of gravity above the point of safety in operation; also, by the limit in the length of piston-stroke, which reduced the leverage of the crank-action as the diameter of the wheels was increased, and further by the mechanical difficulties in the construction of such large wheels. The development of passenger-traffic led to increase in the weight of passenger-trains, consequently to increase in size of boilers and engines and in the whole weight of the locomotive. But with in-

[1] On the Bristol & Exeter Railway, seven-foot gauge, in 1853, a tank-locomotive with single drivers nine feet in diameter made 81 miles an hour.

creased steam-efficiency, it became possible to maintain a satisfactory rate of speed with smaller driving-wheels; so that six feet, or rarely six feet and a half, is now their maximum diameter.

For economic efficiency in freight-traffic, it is more essential that the entire weight of the locomotive should be made available for adhesion. For this purpose, the forward pair of carrying-wheels was coupled by side-rods to the rear wheels, which were directly connected with the piston-rods. But with the demand for increased tractive power, the barrel of the boiler was lengthened in front. The forward pair of wheels was then moved farther back and, in place of the rear wheels, were connected directly with the piston-rods. As speed was of less importance in freight-traffic, the driving-wheels remained of comparatively small diameter, in order to preserve the leverage of the crank-action. The greater dimensions of the engines increased the weight of the smoke-box end, and the accompanying length of overhang caused a pitching motion that was obviated by placing a third pair of wheels farther forward, not connected with the engines and therefore with a relative reduction of the weight available for adhesion. The differentiation of a type of locomotives with a single pair of driving-wheels for passenger-service and of another type with coupled driving-wheels for freight-service existed on European roads, long after the single pair of driving-wheels had disappeared from service on railroads in the United States.

A far greater departure from European practice originated in the United States with the use of the center-bearing truck or, in British railway parlance, the bogie. It served the useful purpose of reducing the rigid wheel-base from the length between the front and rear pairs of wheels, firmly attached to the engine-frame, to the distance between the centers of the coupled driving-wheels. This device was well suited to the frequent curves of short radius and the lightly built track which characterized the American roads of that period, but was not so important upon the European roads, that were more substantially built and on an easier alignment. As this truck was so placed as to support the center of the smoke-box, it interfered with the position of the engines, which were then moved to the outside of the frame and connected to crank-pins on the driving-wheels. The inside-connected engines, with the objectionable cranked axle, have been superseded on American roads by the outside-connected locomotive, and the obvious advantage of this design has induced its general adoption elsewhere.

The desire for a closer adaptation of type to environment, has led to other differences in wheel-arrangement; the most important being the introduction of a pair of low wheels back of the fire-box, to relieve the weight of the overhang at that end. All of these designs, however, are but variations of the original American outside-connected locomotive, which has gained general recognition as a successful example of the economic use of the multi-tubular boiler with forced draft, in connection with the simple reciprocating engine, to develop power in a mobile tractor.

There is a much greater variation in wheel-arrangement on locomotives of the ordinary types in the United States than either in the types of boilers or of the engines proper. The nomenclature, as to wheel-arrangement in use in this country, as given in Appendix II, Table XIII, has been generally accepted elsewhere. The locomotives in service in the United States, in the years 1911 to 1914, are grouped in Table XII as to wheel-arrangement in ten classes, of which five may be disregarded, as simply experimental designs. The locomotives in the remaining classes, in 1914, are tabulated as follows:

A. All driving-wheels	8,496
B. One pair of carrying-wheels, front	25,268
C. Front truck	18,702
E. One pair of carrying-wheels, front and rear	4,911
F. Front truck, one pair rear	5,980
Total	63,357

Class *A* includes mainly switching- and tank-locomotives.

Class *E* includes mainly heavy freight-locomotives.

Class *F* includes mainly heavy passenger-locomotives.

By far the larger number, about 70 per cent., is included in Classes *B* and *C*. Class *B* is the type in ordinary freight-service, and Class *C* in passenger-service.

There were but 153 locomotives in the remaining five classes. Of the total number in Class B, 20,227 out of 25,268 were "eight-wheel connected," and 5013 were "six-wheel connected." In Class C, out of 18,702, there were 10,812 "six-wheel connected," and 7157 "four-wheel connected." So it may be inferred that, for general use in freight-service, the six-wheel and the eight-wheel connected arrangements are preferred, and for passenger-service the four-wheel and six-wheel connected arrangements; all being provided with a front truck. The number of "Mikado" locomotives (2–8–2), used in heavy freight-service, increased from 671, in 1911, to 1159, in 1913, and to 3287, in 1914. As far as experience has gone with the Mallet type, 594 out of 775, in 1914, had one pair of front wheels and one pair of rear wheels. Of these, 464 had driving-wheels in two groups of six wheels each, and 118 had two groups of eight wheels each.

The features of design for the transmission of steam-pressure in the cylinders to the driving-wheels of a locomotive, bring into prominence the ingenious application of the mechanical powers in changing reciprocal into rotary motion, especially in the distribution among the driving-wheels of the adhesive weight of the locomotive. Here the relation of the potential steam-pressure to the adhesive weight is an important consideration. For this is the final test of the combination of all the factors in the production of tractive power, as shown by the dynamometer and stated in pounds of draw-bar pull.[1]

Recent Improvements in Locomotive Design. The Articulated Locomotive

Thirty-five years ago, the boiler and engines of the ordinary American locomotive were attached to a bar-frame between the driving-wheels, which were spaced at a maximum distance of nine feet between centers. As the fire-box was between the frames, the grate-area was about three feet wide and six feet long and the maximum heating-surface was about 1300 square feet, which at the usual steam-pressure established a maximum of eighteen inches for the diameter of the cylinders. In 1881, Mr. T. N. Ely, of the Pennsylvania Railroad, designed a locomotive with the foundation-ring of the fire-box on top of the frames; thereby adding eight inches to the width of the fire-box and permitting the grates to be as long as could be fired by hand, while the heating-surface was increased to 2500 square feet. In 1895 the Baldwin Locomotive Works introduced another design, known as the Atlantic type, in which the fire-box was extended farther back of the driving wheels and supported by a pair of trailing-wheels. This permitted the fire-box to be made as wide as clearance-limitations would allow. In 1901 this design was further developed for passenger-service in the "Pacific" type, with three pairs of driving-wheels.[2]

Twenty-five years ago, the largest locomotive in service weighed about 154,000 pounds, with 34,000 pounds tractive power, and this represented the improvement effected in sixty years. In this period, the purpose had been to attain increased tractive capacity. The details of construction had been improved and the number of wheels increased, but a pound of draw-bar pull required the same fuel-consumption as it had a quarter of century before. From 1889 to 1899, the total weight of a locomotive increased from 154,000 pounds to 232,000 pounds, with a proportionate increase of tractive power. Now, there are locomotives of the same two-cylinder type with 50,000 pounds greater tractive power than had been attained in 1899. The first systematic plan to secure the utmost power of locomotives, within given limitations as to weight and clearance, was made in 1895 with a passenger-locomotive of the usual American eight-wheel type. This locomotive weighed 116,000 pounds, of which 74,500 pounds was on the driving-wheels, and with 21,290 pounds' tractive power. Up to 1902, there were few locomotives with higher tractive power than 40,000 pounds.

[1] See Appendix II, Table XVIII, for formulas for determining the tractive power of locomotives.

[2] A locomotive of this design was built by the Baldwin Locomotive Works in 1913, with cylinders 26 inches diameter and 26-inch stroke, driving-wheels 80 inches diameter, 4,525 square feet heating-surface, 38,300 pounds' tractive power, and total weight of 189,500 pounds.

The most recent design for passenger-service, knows as the "Mountain" type, has a four-wheel truck, eight driving-wheels and a pair of trailing-wheels. It has 240,000 pounds' weight on the driving-wheels, with 58,000 pounds' tractive power, or nearly three times as much power as the standard passenger-locomotive of twenty years before. In a type of freight-locomotive built in this country for the Japanese railways, and therefore called the "Mikado" type, the adhesive weight has been proportionately increased by substituting a pair of leading-wheels for the truck, carrying the rear end of the fire-box on a pair of trailing-wheels, and concentrating the greater part of the weight upon a group of eight driving-wheels. In the "Santa Fé" type, the weight is distributed among ten driving-wheels. With a given weight per pair of driving-wheels, a locomotive of this type can develop tractive power 25 per cent. greater than one of the "Mikado" type, and have equally high steaming capacity in proportion to adhesion.[1]

For freight-service on easy grades, exceptionally heavy locomotives of the American type are preferred, with six, eight, or even ten coupled driving-wheels. Simple cylinders, operating at 200 pounds' pressure, have reached a diameter of thirty inches, with main axles thirteen inches in diameter. The main crank-pins, rods and other moving parts are of proportionate size, and their weight has reached the point where proper counter-balancing becomes difficult. Locomotives with four-cylinder simple engines have been tried, but the space between the frames has so limited their capacity that it is impracticable to provide them with the power given by the two-cylinder simple engines.

The effect upon the track of the vertical unbalanced forces in a two-cylinder simple engine has yet to be obviated. The more powerful locomotives, with cylinders from 27 to 29 inches in diameter, give maximum piston-thrusts of about 117,000 pounds, with wheel-loads higher than ever before and with reciprocating parts of much greater weight. The four-cylinder balanced compound was designed as a possible solution of this problem. A three-cylinder simple engine is said to have been successfully tested in experimental service, with a large cylinder between the frames connected to a cranked axle, and the outside cylinders to the back driving-

[1] Principal dimensions of locomotives built in 1915 by the Baldwin Locomotive Works for the Erie Railroad Company:

"Mikado" type.

Cylinders, 28 inches by 32 inches. Working pressure, 170 pounds.

Driving-wheels, 63 inches diameter. Rigid wheel-base, 16 feet 6 inches.

Weight on driving-wheels, 236,950 pounds. Front wheels, 30,200 pounds. Back wheels, 54,910 pounds. Total weight, 322,060 pounds.

"Santa Fé" type.

Cylinders, 31 inches by 32 inches. Working pressure, 200 pounds.

Driving-wheels, 63 inches diameter. Rigid wheel-base, 22 feet. Total, 41 feet 3 inches.

Weight on driving-wheels, 327,250 pounds. Front wheels, 24,450 pounds. Back wheels, 56,000 pounds. Total weight, 407,700 pounds. Tractive power, 83,000 pounds.

axle. It offers a more even turning movement than is the case with the two-cylinder engine, with better counter-balancing and less destructive effect upon the track. The power obtained from a two-cylinder engine, with cylinders 27 inches in diameter and with maximum piston-thrust of 117,000 pounds, can be obtained from a three-cylinder engine with cylinders 22 inches in diameter and with a maximum piston-thrust of 78,000 pounds. This decrease of 33 per cent. in thrust means a corresponding reduction in the weight of the machinery, particularly of the reciprocating parts. It is thought that such a three-cylinder engine would be especially efficient in high-speed passenger-service.[1]

Both the simple and the compound engine were gradually increased in cylinder-capacity and tractive power until the further enlargement of the low-pressure cylinders in the four-cylinder compound engines had reached the clearance-limit; the permissive diameter being 30 inches, equivalent to 21 inches in the high-pressure cylinder. In the eighties, the American Master Mechanics Association had fixed the maximum adhesive weight at 12,000 pounds on each driving-wheel, yet wheel-loads have now reached 35,000 pounds. A further important departure from conventional design was originated by Mallet in his compound articulated locomotive, in which it was sought to increase the tractive power within the clearance-restrictions, without lengthening the rigid wheel-base or increasing the axle-weights. This purpose is accomplished by a modification of the principle of the American long car-body supported by swiveling trucks.[2]

In the articulated locomotive, the rear end of the boiler is rigidly attached to a truck-frame that carries the high-pressure engines; the low-pressure engines being placed upon a forward truck-frame, well ahead of the front end. This end of the boiler rests upon a saddle, center-bearing on the truck-frame, which permits of a restricted lateral motion. In each truck-frame is a group of three or four driving-axles. The forward truck swivels on an extension that is pivoted to the rear frame; the play in the articulation being taken up by strong lateral springs. The exhaust-steam from the high-pressure engines is conveyed to the low-pressure engines by a pipe with an intervening ball-and-socket joint and slip-joint. By the same device, flexibility is given to the superheater connections and, by metallic hose, to the injector and feed-water connections.

The Mallet locomotive, with two groups of three axles each, was introduced into the United States in 1904 on the Baltimore & Ohio Railroad for "pusher" service in coal-traffic on heavy mountain-grades. The Erie Railroad followed with heavier locomotives, having two groups of four

[1] Statistics as to performance and principal dimensions of certain high-speed passenger-locomotives are given in Appendix II, Table XIV.

[2] In this respect, the articulated locomotive is a development of the Fairlie locomotive of about 1870, in which two boilers were placed back to back on a single frame supported upon driving-wheel trucks, each carrying its own engines with steam-pipes connected by swiveling-joints.

axles each; and still more powerful examples of the same wheel-arrangement were built for the Delaware & Hudson Railroad Company, each of which did the work of two "Consolidation" locomotives.[1]

The Mallet locomotive was then adapted to road-service. The passage around sharp curves was facilitated by the addition of leading and trailing wheels in pony-trucks, radially attached to the engine truck-frame, and by devices for lubricating the flanges of these wheels. Locomotives of this type, with three axles in each group, were built in 1906 for the Great Northern Railway Company.[2]

In 1909 the Atchison, Topeka & Santa Fé Railway Company was operating locomotives in passenger-service with 4–4–6–2 wheel-arrangement and 73-inch driving-wheels, and in freight-service with 2–8–8–2 wheel-arrangement and 63-inch driving-wheels. The long forward overhang of these locomotives resulted in such lateral play as to compel considerable enlargement of clearance-limits around sharp curves. To obviate this, resort was had experimentally to articulating the boiler also, at the front of the combustion chamber and just ahead of the articulation of the truck-frames. Two expedients of this character were devised. One was a double ball-and-socket joint in connection with a slip-joint in the outer shell. The other was an "accordion" arrangement of rings, ten inches broad, in V-shaped joints, riveted on the inside and bolted on the outside edges, which effected the desired flexibility. In both designs, the combustion-chamber was prolonged in a drum, flanged as a slip-joint, into the forward section of the boiler, which was rigidly attached to the forward truck-frame.[3]

[1] Baltimore & Ohio Railroad locomotives:

Cylinders, 20 inches and 32 inches by 32 inches stroke. Steam-pressure, 235 pounds. Weight, 334,000 pounds.

Erie Railroad locomotives:

Cylinders, 25 inches and 39 inches by 28 inches stroke. Steam-pressure, 215 pounds. Weight, 409,000 pounds. Drivers, 4 feet 3 inches diameter. Rigid wheel-base, 14 feet 3 inches. Tractive power, compound, 94,800 pounds.

Delaware & Hudson Railroad locomotives:

Cylinders, 26 inches and 41 inches diameter by 28 inches stroke. Steam-pressure, 228 pounds. Weight, 402,000 pounds. Drivers, 4 feet 4 inches diameter. Rigid wheel-base, 14 feet 9 inches. Tractive power, compound, 105,000 pounds. Tractive power, simple, 126,000 pounds. Total length, with tender, 90 feet 6 inches. Height, 16 feet. Width, 11 feet 4 inches.

[2] Great Northern Railway locomotives:

Cylinders, 21.5 inches and 33 inches by 32 inches stroke. Steam-pressure, 200 pounds.

Weight on drivers, 316,000 pounds; on pony-trucks, about 20,000 pounds each.

Drivers, 4 feet 7 inches. Rigid wheel-base, 10 feet. Total wheel-base, 30 feet.

Length over all, 44 feet 10 inches; with tender, 73 feet.

Tractive power, working compound, 71,600 pounds.

Reversing gear operated by compressed air.

[3] These locomotives were of the 2–6–6–2 wheel-arrangement, with superheating and reheaters. Cylinders, 24 inches and 38 inches by 28 inches stroke. Steam-pressure, 220 pounds. Drivers, 69 inches in diameter. Tractive power, compound, 61,500 pounds.

In working locomotives "compound," it has been customary to carry a steam-pressure of from 200 to 230 pounds, in order that the diameter of the low-pressure cylinders should be kept within the clearance-limits. An experimental Mallet locomotive, built by the Pennsylvania Railroad Company, was intended to work "high-pressure" only, at a pressure of but 160 pounds, by enlarging the diameter of the boiler and using a superheater. This locomotive had an adhesive weight of 437,500 pounds and total weight of 482,500 pounds, with theoretical tractive power of 99,200 pounds. The Pennsylvania system has made but little use of the articulated locomotive.

The most powerful locomotive in service in the world, up to 1916, was built by the Baldwin Locomotive Works for the Erie Railroad Company. It is of the triple articulated type, with the tender as the third articulated section; the wheel-arrangement being 2–8–8–8–2. It has six cylinders; the middle pair working high-pressure. One cylinder of this pair exhausts into the forward low-pressure pair and the other into the rear pair, which is attached to the front tender-truck frame. The front cylinders exhaust into the stack, and the exhaust from the rear pair, after passing through a feed-water heater, escapes through a pipe in the back end of the tank. The variation in the adhesion, due to the varying load in the tender, is not important in pusher-service. The locomotive has a superheater and a mechanical stoker, which handles coal from the tender to the furnace without the intervention of the fireman.[1]

This locomotive has exerted normally 160,000 pounds tractive power, increased to 200,000 pounds by mechanical draft. On a tonnage-test, it hauled a train of 250 loaded coal-cars for 23 miles over ascending-grades, reaching at one point 0.9 per cent. on a five-degree curve. The total length of the train was 8547 feet or 1.6 miles, and its weight, exclusive of the locomotive, was 17,912 tons. The maximum speed was at the rate of 14 miles an hour, and the highest registered draw-bar pull was 130,000 pounds. With but one engine-crew, it has the capacity of three large eight-wheel coupled locomotives.

Such a tractor may be considered a triumph of engineering skill in design and construction, but from a practical standpoint, it seems to have exceeded the limits of economic efficiency. Yet the limits of magnitude in the construction of articulated locomotives have not been reached, at least in design; for there has been designed a "quadruplex" locomotive, mounted on four groups of four driving-axles each, including the tender, with one

[1] Principal dimensions: Cylinders, 36 inches by 32 inches stroke. Working pressure, 210 pounds. Driving-wheels, 63 inches. Wheel-base, rigid, 16 feet 6 inches; driving, 71 feet 6 inches; total, 90 feet. Weight (on driving-wheels), 761,600 pounds. Total weight, loaded, 853,050 pounds.

The weight of the tender has been more recently utilized for traction by placing it upon "Mogul" running gear, actuated by superheated steam from the locomotive-boiler. "Southern Railway Duplex Locomotive." — Railway Mechanical Engineer, March, 1917, p. 121.

pair of lead-wheels and one of trail-wheels, and a total length between extreme centers of 118 feet. Its estimated weight, in running order, is 885,000 pounds; tractive power, 200,000 pounds; working-pressure, 215 pounds. With smoke-box and combustion-chamber, the total length of boiler is 80 feet; with an "accordion" joint in the combustion-chamber, intermediate between two sections of tubular boiler. The engine-cab is in front.

In four years, from 1910 to 1914, the number of locomotives in service of the Mallet or articulated type had increased from 200 to 775. It has apparently met with favor where local conditions as to gradients and tonnage had exhausted the economic capacity of the ordinary types of locomotive. On the Pennsylvania Division of the New York Central Lines, where the traffic is principally in coal, 60 Consolidated locomotives, costing $17,000 each, have been displaced by 26 Mallet compounds. They handle the whole tonnage at average speeds and with 35 per cent. less fuel, over long grades of one in 200, and others even steeper, and around eight-degree curves, without assistance from helpers. The reduction in the number of trains has served to postpone building second track that would cost millions.

An articulated locomotive, with one pair of lead-wheels, one of trailing-wheels, and two groups of eight driving-wheels in each group, developed its maximum power at seventeen miles an hour. At twenty-five miles per hour it exerted 950 horse-power at the draw-bar. Locomotives of this type, designed for "pushing" service on grades of over two per cent., and rated at 115,000 pounds' tractive power, when working compound, have handled a train of 7180 tons gross, on the Virginian Railway, on a six-tenths per cent. grade, requiring a draw-bar pull of 110,000 pounds. On lighter grades and at higher speeds, over 3000 indicated horse-power has been obtained. Other tests of this type have shown an increase of 13.5 per cent. in tonnage and increased speed of 4.3 per cent., with a saving of water of 11.1 per cent. on practically the same fuel-consumption per ton-mile.

In 1912, experience with the Mallet locomotives in road-service on different lines was summed up in the American Engineer and Railroad Journal as follows: With 103 in service, two did the work of three of the Consolidation type; with 25, the number in service was reduced one-half, the number of crews one-third and the fuel-consumption also. With 10 Mallet locomotives, the fuel-consumption per 100 ton-miles was 39.2 against 69.8 pounds with Consolidation locomotives, and, on another line, with the same number of Mallet locomotives having 0–6–6–0 wheel-arrangement, three took the place of five of the Consolidation type, with saving of 22 per cent. in coal-consumption, one fireman furnishing steam for their full rated capacity. In general, the Mallet locomotives have been found equally reliable with other large locomotives; the cost per ton-mile being reduced nearly 30 per cent. with increase in ton-mile movement of about 67 per cent. The cost of repairs is probably double that of the Consolidation type.

When we think of the average locomotive in the United States as weighing 77 tons and see it speeding along, self-contained as to the production of energy and its conversion into tractive power, we may well view it as a marvel of mechanical efficiency. Still more may we wonder at the performance of the monstrous articulated locomotive, 88 feet in length and weighing 225 tons, with 224 tons on the driving-wheels.

Additional Features and Adjuncts

Accessory appliances to a locomotive have greatly increased since the time when they included only the feed-pump, the bell and whistle, the spring-balance by which the single safety-valve was controlled, the gauge-cocks and the hand-brake. It would be difficult for the modern engine-driver to estimate the varying boiler-pressure by lifting the spring-balance with his thumb or to tell the height of water in the boiler at night by the difference in the hissing sound of water or of steam from the gauge-cocks. But the steam-gauge and the glass water-gauge, as well as the cab-lamp, were innovations not so many years ago, as were also double safety-valves.

The steam-whistle, in the form of a trumpet, is said to have been invented by George Stephenson in 1833. Up to that time, signals had been given by lifting up the spring-balance attached to the safety-valve. In the United States, the first mention of the whistle is in connection with a locomotive built by Rogers, Ketchum & Grosvenor in 1837. Because of its whistle, this locomotive was bought for the first railroad in Ohio, which was then under construction. The track was laid to suit the gauge of the locomotive, which was 4 feet 10 inches. In consequence, this gauge was made compulsory by statute in the State of Ohio.

On the early locomotives, the foot-plate, or foot-board, was merely inclosed by a hand-rail. Cabs were unknown until 1848, when an engine-driver on the Western Railroad of Massachusetts devised one of canvas as a protection from the weather.[1]

Before the introduction of the sand-box, it was the duty of the fireman and the wood-passer to prevent slipping by throwing sand, from buckets, on the track, while walking beside the locomotive or standing on the pilot or "cow-catcher," which is a distinctively American device.[2]

The reflector headlight is said to have been first introduced on the Boston & Worcester Railroad in 1840. It originated as a safety-device for

[1] "The Eastern Railroad," F. B. C. Bradlee.

[2] Wood-burners were in general use on roads in the United States for many years, and in the Southern States until about 1880. The use of coal was originally confined to the immediate vicinity of the mines. Coal-burners were introduced on the Eastern Railroad of Massachusetts in 1860.

night-runs, when trains out of time ran against each other for the half-way post between sidings. The headlight lost its value for this purpose as train-dispatchers relieved engine-drivers and conductors of the responsibility for making meeting-points for delayed trains. On double-track, the glare of the headlight becomes rather a nuisance than a benefit to the engine-drivers of opposing trains. This is particularly true of the use of electric searchlights which, in some of our States, has been made compulsory. In all other countries, simple signal-lights, similar to our tail-lights, are still sufficient for the needs of train-service.

Far more important than the headlight, has been the substitution for the feed-pump of that mechanical paradox, the injector. In the injector, patented in 1858 by H. T. Giffard, a French engineer, a jet of steam imparts to a surrounding column of water, in a pipe, sufficient velocity to force the water into the same boiler from which the steam was taken. In addition to raising the temperature of the feed-water, it supplies the boiler while the locomotive is at rest. Many a collision was formerly caused by locomotives having to leave trains in sidings and then run out on to the main line to "pump up."

A still greater improvement was the introduction of the air-brake; although this accessory pertains more directly to train-equipment, as well as the appliances for steam-heating passenger-trains and power for electric lighting. All these train-appliances, however, in so far as they cause steam-consumption, are a draft upon the tractive power of the locomotive.

Among other modern accessories are the jet-blower, to create a draft when the locomotive is at rest; valves to relieve the back-pressure in the cylinders when the locomotive is drifting, with steam shut off; spark-arresters that prevent a shower of sparks from illuminating the onward progress of the train and scattering fire along its path. Mention may also be made of sight-feed lubricators in the cab, of oil-pumps and of other auxiliary means of lubrication while the locomotive is in motion. It would be difficult to make long runs at high speed without stopping, but for the use of hard-grease cups wherever possible, instead of oil. All of these standard improvements in the mechanical efficiency of the locomotive are in general use in this country.

The design of tenders has also kept pace with the development of the locomotive. As the load of fuel and water was increased, two four-wheel trucks of the type in use under freight-cars, though of larger dimensions and more accurately fitted, have been substituted for the original running-gear on three axles, working in pedestals fixed to the tender-frame. Tenders carrying 6000 to 8500 gallons of water and 10 to 15 tons of coal weigh empty 23 to 33 tons and, when loaded, from 60 to 82 tons. The type in general use is fitted with a horse-shoe tank surrounding the coal-space. Tenders attached to locomotives which are provided with grates above the trailing-wheels have water-bottoms, with the coal-space above them at the level of the higher furnace-doors. The "Vanderbilt" tender, with circular tank, holds 12,000 gallons of water and, with 20 tons of coal, weighs 206,400 pounds. For high-speed trains, running over 45 miles an hour, water is scooped up from troughs, or track-tanks, 1000 to 2000 feet in length, located on level tangents.[1]

This wonderful growth in motive-power efficiency, the creation of inventive genius in locomotive design, could not have been achieved, had there not been an equal advance in the metallurgical arts, in mechanical appliances and in machine-tool production. Improvements in methods of construction have accompanied improvements in design. In the earlier locomotives, the tubes were of copper or of brass and the fire-box of copper, as is still usual in European practice. But in this country, charcoal-iron and special grades of steel have been substituted with advantage, for the higher pressure to which our boilers are subjected. With the experience gained in the treatment of basic steel, that material is now in general use. Mechanical details are more thoroughly considered in the connection of boiler-plates by welt-straps, in a more judicious arrangement of riveting, and in the attachment of braces, crown-sheet bars and tube-fastenings, as also in the more careful use of calking tools and in the use of electric welding, pneumatic riveting and other appliances using compressed air. The introduction of water-tubes and superheaters has also required a higher grade of skill in the boiler-making art. This attention to mechanical details has greatly contributed to the strengthening and endurance of boilers, enforced as it is by more thorough inspection; so that the explosion of a locomotive-boiler is now of rare occurrence, notwithstanding the increase of from 80 to 200 pounds to the square inch in the working steam-pressure.

Similar excellence in character and workmanship has been displayed in machinery-details. The use of high-grade steel alloys has permitted a reduction of as much as 2,500 pounds in the weight of moving parts, with a corresponding relief in their effect upon track and tractor. On large locomotives the weight of the two cylinders has been decreased some 3500 pounds by the use of cast-steel. Cylinder-castings are made reversible, so that the same pattern may serve for either a right-hand or a left-hand engine. The wear on the lower surface in the cylinders by the weight of the piston is obviated by lengthening the front end of the piston-rod and extending it through a bearing in the front cylinder-head. Metallic piston-rings are kept tight simply by steam-pressure, which is also made available for relieving the wear of the valve-seats in the steam-chest by balancing the flat slide-valve; while the objectionable feature of long steam-ports in cylinders of great diameter has led to the substitution of piston-valves. Here, as in the matter of boilers, mechanical excellence and thorough in-

[1] See Chapter V, Part II, p. 265.

spection are shown by the decreasing number of accidents attributed to locomotive-defects.[1]

The strain upon the engine-driver's strength in reversing the valve-gear of heavy locomotives has been relieved by the aid of compressed air. Asbestos cloth has taken the place, as a boiler covering, of wooden lagging, which was liable to become charred and to take fire from a lodging spark. The labor of cleaning locomotives has been lessened by reducing the area of brightened surfaces and polished brass fittings with which they were once resplendent.

Maintenance and Standardization

Shop-efficiency is closely associated with motive-power efficiency as to mechanical excellence and operating economy. In this connection, it is well to dissociate construction from maintenance. The former, in its economic relations, has so little to do with railway operation that, in a discussion of shop-efficiency, it may be but briefly considered. In locomotive-building on a large scale, as in other manufacturing industries, professional experts may be serviceable, and especially on piece-work, in diminishing useless physical effort and idle time of machine-tools; also in speeding up machinery. The greater the output of such a shop, the wider is the field for the profitable application of such methods. Conversely, they are less valuable with a small output.

It is doubtful whether it is advisable for a railroad company to build its own equipment, unless the annual replacement is on a scale commensurate with the provision of a suitable plant that can be fully employed in such work alone. The loss in obsolete patterns and in duplicate parts is proportionately heavier in a railroad shop than when it can be distributed over a larger output; while the temptation to find work to keep a full force on the payrolls, as construction becomes slack, does not exist in a commercial establishment. Nor should the interest upon the value of the land-site and the cost of the necessary buildings be ignored in determining the relative economy of buying or of building equipment, as well as the probable outlay for depreciation and betterment of buildings and appliances. The total number of locomotives built in the United States in 1914, including a number sent to Canada, was 2235. The total number in service that year increased by 1232; so that not over 1003 were required for replacement. From these statistics it would seem that there are few railroad companies that could profitably engage in locomotive construction.[2].

Railroad repair-shops are in a class by themselves as to shop-efficiency. It is more of an object to have repairs done expeditiously than cheaply,

[1] The accidents from locomotive-defects, noted in the Report of the Interstate Commerce Commission for 1915, were 856 in 1912, with 91 persons killed and 1055 injured; and in 1915, 424 accidents with 13 persons killed and 467 injured.

[2] Ry. Statistics of the U. S. for 1914. — Slason Thompson, p. 40.

for the locomotive earns nothing while it is still. Much of the work is of a character known as roundhouse repairs, which is largely a matter of manual labor, applied under conditions which necessarily involve loss of time in going to and from the shop, in taking down and putting up parts of machinery while locomotives are under steam, and in other ways familiar to operating officials.

The extent to which labor-saving appliances and tools can be economically employed in an ordinary repair-shop depends upon the number of locomotives that need such a shop for maintenance in fair running order. As a general thing, about one-tenth of the locomotives on any road or division are out of service at one time; and this is the measure of the kind of shop which should be provided for their maintenance. If an expensive machine-tool is to stand idle for half of the time, its efficiency is reduced to that extent, while the interest on its cost and the annual depreciation in its value are running on continuously. Unless it can be shown that the use of such a tool will make it possible to effect a proportionate reduction in the cost of labor, its purchase does not contribute to economic efficiency. Rather than provide each small repair-shop with such costly tools, it would be better to establish central shops for important repairs and general overhauling, where expensive appliances might be kept constantly employed, and leave the ordinary running-repairs to the division shop, intrusting the character of the work as well as the efficiency of the shop-hands to the supervision of intelligent and experienced foremen.

The success which has attended the application of standardization to machinery-output in factories, has brought out enthusiastic advocates for its extension to operations in which handwork is a more important element. The profitable employment of such methods in railroad repair-shops varies with local conditions. As a general rule, standards are useful for all parts that are simple and numerous. For instance, standard screw-threads and other standards are adopted for bolts and nuts, and this requires that careful attention should be given to dressing drills and other tools. But the more varied the parts are in any mechanism, the more difficult it becomes to establish satisfactory standards for them all. This is especially the case as to parts with large wearing surfaces. With these it may be cheaper to take up lost motion by individual fitting than to condemn both driving-axle and journal-box, for example, in order to preserve standard dimensions. In complicated machines, it is far easier to establish standards than to maintain them. The value of standardization consists in rigorous conformity to dimensions. Variations that may be negligible if the units are few in number, become a serious hindrance to the economic value of interchangeable parts, where many of such units are in service. These remarks do not apply to the duplication, as an emergency measure, of important parts roughly machined to approximate dimensions.

The advantages to be derived from standards in details are not so apparent in general design. Standardization means rigorous conformity, and uniformity is a barrier to further improvement. Each progressive step then implies the scrapping of existing tools or appliances. This statement applies with force to designing machinery for purposes that are continually becoming more extended or diversified. The description given in this chapter of the development of the locomotive, furnishes a case in point. If the locomotive of the ordinary American type had become definitely established as the *ne plus ultra* of locomotive design, and classified types of this design had been made standard as to all parts and dimensions, the limits of motive power efficiency would have been irrevocably fixed, and the hope of any further reduction in the cost of motive power would have vanished. It has, therefore, been fortunate that inventive genius has not been thus paralyzed, but that it has still the opportunity to increase the efficiency of our locomotives, untrammeled by the restrictions that would have been imposed upon it by standardization in design.

Locomotive Tractive Power in the United States

A comparative statement of the total theoretical tractive power of the entire locomotive-equipment of our railway system appeared in Bulletin No. 31 of the Bureau of Railway Economics. This comparison was made for each year from 1902 to 1910, and the results for the years beginning and ending this period are as follows:

	Locomotives	Tractive Power	Average Power
	Number	Pounds	Pounds per Tractor
1902	41,225	768,502,779	18,641
1910	58,947	1,588,894,480	26,955
Increase	17,722	820,391,701	8,314
Per cent.	43	106	44

From this statement, it would appear that the theoretical efficiency of the total tractive power of the railway system of the United States had been more than doubled in eight years; and that the number of tractors and their average individual efficiency had increased nearly one-half. This statement may be compared with one compiled from the statistical reports of the Interstate Commerce Commission,[1] as follows:

[1] See Appendix II.

	Locomotives	Tractive Power	Average Power
	Number	Pounds	Pounds per Tractor
1910	58,947	1,588,894,480	27,282
1914	63,510	1,931,953,982	30,420
Increase	4,563	343,059,502	3,138
Average increase per annum			
1902–1910	2,215	102,548,962	849
1910–1914	1,141	85,764,875	784

Apparently, the increase per annum from 1902 to 1910, in number of locomotives and in average tractive power, was not maintained in the next four years. From this comparison, however, there are excluded unclassified locomotives; also locomotives of the articulated type, as follows:

	Number	Tractive Power	Power per Tractor
1910	200	14,407,261	72,036
1914	775	61,241,128	79,021
Increase	575	46,833,867	6,985

Using the conventional "standard locomotive" of 25,000 pounds tractive power as a unit of comparison, the average articulated locomotive of 1914 exceeds three of the simple type in tractive power.[1]

It is further to be noted that, while there was an average annual increase of 752 locomotives from 1890 to 1900, of 2128 from 1900 to 1910, and of 2380 in 1911 the increase in 1912 was only 875, and 1116 in 1913. This indicates either that the locomotive-equipment had gained on the traffic-requirement or that there was a diminution in the purchasing-power of the railroad companies. In 1913, there was an increase of 1382, of which 828 were for freight-service and 216 for passenger-service, 247 for switching and 91 unclassified. Eighty-two per cent. of the total number were in regular-train service, and of these nearly one-fourth were in passenger-service. The remainder were either classed as switching-locomotives or were unclassified; the latter being for the most part in use on work-trains. Over eleven thousand, or 17 per cent., were thus employed in service unproductive of revenue.[2]

From the statistics given in Appendix II, Table V, it appears that, while the number of locomotives, exclusive of the articulated type, increased 12.4 per cent. from 1908 to 1914, their total tractive power increased 28.5 per cent. A higher ratio of increase was maintained with respect to the

[1] See Appendix II, Table XVIII.

[2] See Appendix II, Table I.

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component factors of evaporative and adhesive capacity; so that a due relation was preserved in their efficiency as steam-generators, as power-mechanisms and as tractors. The general increase in motive-power efficiency is made apparent in a statement of train-tonnage on forty-five of the principal roads in this country in 1913, which showed that on sixteen of these the average freight-train load had increased thirty per cent. in the previous five years.

As in the previous chapter,[1] a comparison was made of the relative volume of traffic in the three territorial districts into which our railway system has been divided in the statistical reports of the Interstate Commerce Commission since 1911, it is of some interest to note the relative distribution of motive power in 1914.[2] The ratio of number of locomotives to length of line operated, indicates the relative density of traffic in those districts. The Eastern District, with 26 per cent. of the total mileage, had 45.6 per cent. of the total tractive power; the Southern District, with 19 per cent. of that mileage, had 16.2 per cent. and the Western District, with 55 per cent. of the mileage, had 37.5 per cent. of the total tractive power. Of the total tractive power in the Eastern District, 74 per cent. was applied on sixteen roads; in the Southern District, 73 per cent. on seven roads; in the Western District, 74 per cent. on fifteen roads. None of these thirty-eight lines were operated with less than five hundred locomotives, and together they controlled 74 per cent. of the motive power of the entire system.[3]

The average tractive power per locomotive in the Eastern District considerably exceeds that in the others, including those of the articulated type. The extent to which this type has been recently introduced into our railway system is shown separately.[4] While the use of the Mallet or articulated locomotive is not general in the Eastern and the Southern districts, it is becoming a substantial element of the motive power in the mountainous regions of the Western District.

Economy of Service

Although the locomotive as a tractor has attained an efficiency of approximately 90 per cent., its economic efficiency is to be determined by the results of the application of its tractive power in train-service. There are two elements, mileage and tonnage, in this service, passengers being substituted for tons in passenger-service. For transportation purposes, these two elements are employed as factors for ascertaining the sum total of the service rendered; that is, in passenger-miles for passenger-service and in ton-miles for freight-service.

[1] Chap. II, p. 20.
[2] See Appendix II, Table VII.
[3] See Appendix II, Table X.
[4] Appendix II, Tables VI, VIII, IX, and XI.

In 1913, there were 63,378 locomotives on our railway system. Of this number, 52,320 were in regular service; 37,924 being on freight-trains and 14,396 on passenger-trains. The service rendered in that year was at the rate of 7,843,663 ton-miles per freight-locomotive and of 2,341,629 passenger-miles per passenger-locomotive. On the basis of mileage, the average was 19,531 miles for freight-locomotives and 42,629 miles for passenger-locomotives.

In 1914, with 38,752 freight-locomotives and 14,612 passenger-locomotives, a total of 53,364, the respective averages, as to service rendered, were 7,368,713 ton-miles and 2,364,644 passenger-miles. With an increase of 828 freight-locomotives, there was a decrease in the average performance of 474,950 ton-miles. With an increase of 216 passenger-locomotives, there was an increase of 23,015 passenger-miles per locomotive.

From the Interstate Commerce Commission reports and from the tables in Appendix II, it will be seen that the average performance per locomotive in the past five years is reported as follows:

YEAR	FREIGHT		PASSENGER	
	MILES	TON-MILES	MILES	PASSENGER-MILES
1910	20,656	7,237,569	41,510	2,171,106
1911	19,603	6,998,740	41,267	2,289,278
1912	18,907	7,134,323	42,489	2,295,902
1913	19,531	7,843,663	42,620	2,341,629
1914	17,941	7,368,713	42,642	2,364,644
Average	19,327	7,368,542	42,105	2,292,512
Per day	52.9	20,045	115.4	6,281
Average per mile run . 379 tons; 55 passengers				

According to these statistics, the daily performance of a freight-locomotive in these five years averaged 20,045 ton-miles, and that of a passenger-locomotive was 6281 passenger-miles; equal to 379 tons of freight or to 55 passengers for each mile run. With forty-ton freight-cars and sixty-seated passenger-cars, this amounts to ten car-loads of freight and one car-load of passengers for each mile run.

An additional factor, however, should be supplied in establishing a standard of motive-power efficiency from these figures; that is, the time occupied in rendering the service. What was the average number of hours per day, throughout the year, in which each and every locomotive in regular service was out on the road between terminals? For, evidently, they were earning nothing except when they were *on the road.* Assuming an average speed of 13 miles an hour for freight-service and of 29 miles an hour for passenger-service, including all stops and delays between terminals, the freight-locomotives were profitably employed, on an average through the year, for 4.07 hours a day and the passenger-locomotives for 3.97 hours. On this basis, the average daily work of a locomotive was respectively 4900 ton-miles or 1058 passenger-miles. The average rates were 0.733 cent per ton-mile and 1.982 cents per passenger-mile. At these rates, the freight-locomotives earned, on a daily average, $36.91, and the passenger-locomotives, $20.96.

The 53,364 locomotives in regular service in 1914 represented an investment of perhaps $1,500,000,000, and an annual interest at five per cent. of $75,000,000. If the motive power represented by this vast sum were employed in manufacturing industries, would its average use for only four hours a day be considered satisfactory? Yet, while a manufacturing plant is usually operated from eight to twelve hours a day, the train-service is conducted day and night. Why, then, should a locomotive be in use only four hours a day?

"Pooling System" in Locomotive Handling

By keeping more continuously in use the enormous investment in motive power, the economic efficiency of our railway system would be largely increased. This end was sought in the introduction of the "pooling system"; that is, by assigning no particular crew to any particular locomotive, so far as applicable under prevailing traffic-conditions. As has been the case with many other advances in railroad efficiency, this effort to increase the profitable use of motive power originated in the United States, and apparently with Colonel T. M. R. Talcott, when General Manager of the Richmond & Danville Railroad.

Prior to 1875, the Richmond & Danville Railroad Company, whose line was of five-foot gauge, acquired control of the North Carolina Railroad, a line of standard gauge. The line from Richmond connected at Greensboro, 189 miles from Richmond, with the North Carolina Railroad which, 93 miles farther, connected at Charlotte with the Atlanta & Charlotte Air Line Railroad, a line of five-foot gauge. This intervening section of 93 miles was, in March, 1875, changed to the same gauge to permit of continuous-train service from Richmond to Charlotte and Atlanta. The need for this change was so imperative that, until additional equipment of the wider gauge could be obtained, the run of 282 miles from Richmond to Charlotte was performed by the same locomotives which had previously covered the line from Richmond to Greensboro, the crews of the North Carolina Railroad taking charge of the trains at Greensboro. Therefore, thirty-six locomotives did the work before performed by fifty-seven, and with a monthly mileage increased from 1667 to 2683 miles.

The result of this emergency measure induced the Pennsylvania Railroad management to experiment in the same way, in 1876, with 27 engines and 42 sets of men. In the same year, on the Illinois Central Railroad, the runs of certain freight-locomotives were lengthened from 117 miles to 210, 228 and 252 miles, and, on one division of 210 miles, a complete pooling-system was established, with 18 or 20 freight-locomotives. The experiment on the Illinois Central Railroad was discontinued after a trial of from four to six months; but on the Middle Division of the Pennsylvania Railroad it proved so satisfactory to the Superintendent, Mr. James McCrea, afterward President of the company, that he subsequently introduced it on the New York Division. The train-crews were kept together, both locomotive-men and train-men, "first in, first out," and no cleaning was done by the firemen.

These experiments in pooling locomotives attracted such attention that they were made a topic for discussion at the annual convention of the American Master Mechanics Association, held at St. Louis in May, 1877. The purpose then uppermost was to obtain increased mileage by long continuous runs of the same locomotive, with relay-crews at the terminals of connecting divisions. Further trials of this plan proved unsatisfactory. The infrequent opportunities for cleaning fires and for inspection led to a divided responsibility between the relay-crews as to fuel-consumption and as to careful handling, and it was this that brought the plan into disrepute. Attention was then directed to gaining average mileage from the locomotives assigned to a single division, and it was this plan of pooling which was principally considered at the sessions of the International Railway Congress at Washington in 1905.

The question, as there presented, was the advantages and disadvantages of the practice, with respect to the efficiency and care of the locomotive. The several ways of handling motive power were classified as follows:

I. Assignment of a specified crew to a specified locomotive.

II. Assignment of two crews in series to a specified locomotive.

III. Assignment of three crews in series.

IV. Assignment of relief crews to single-crew assignments.

V. Assignment of more than three crews to all the locomotives assigned to a specific service.

VI. Complete pooling of all locomotives and crews on any line or division, with temporary assignment of either to meet current requirements.

A distinction was made as to the objects of pooling, whether as an emergency measure in an unexpected increase of traffic, or to provide for an ordinary seasonal increase, or as a general plan of operation. As might have been anticipated, opinions as to all of these matters differed with the varying conditions of environment in different regions or countries. These regions or countries were classified in three divisions, with a separate report from each division.

The report upon the practice in the division including all countries, excepting the United States, Belgium, England and its colonies, Holland, Denmark, Russia, Sweden and Norway, covered 26 managements, 62,810 miles of line and 21,900 locomotives. The conclusions reached in this report were to the following effect:

Complete pooling leads to an appreciable increase in cost per mile and should only be resorted to in case of absolute necessity.

It is preferable to use "interpolated auxiliary crews" (that is, relief crews as in No. IV), or else multiple crews (No. V).

The double-crew system (No. I) is recommended for switching, suburban and shuttle service.

The single crew (No. I) is advisable on fast express-trains.

The complete pooling plan (No. VI) had been exclusively in use on the St. Gotthard Railway since 1886. In three years, the fuel-expenditure had increased 5.5 per cent., cost of lubricants, 42 per cent., and cost of maintenance, 11.6 per cent.; but in the meantime the speed of trains and the weight of locomotives had also been increased.

The report upon the practice in Belgium, England and colonies, Holland, Denmark, Russia, and Sweden and Norway covered 90 managements, of which 60 had replied, with 60,200 miles of line. Twenty-four managements, with 45 per cent. of the total mileage, preferred single crews (No. I). The other 36 managements made partial use of one or more of the several methods of pooling. Of these, there were 20 managements which reported:

8,249	locomotives on single system (No. I)
3,341	locomotives on double system (No. II)
100	locomotives on triple system (No. III)
28	locomotives on mixed system (No. IV)
659	locomotives on multiple system (No. V)
149	locomotives on complete system (No. VI)
12,526	locomotives, of which number 34 per cent. were on one or more pooling plans.

The only instance of triple crews (No. III) was in switching-service at busy stations on three lines in Great Britain.

The report for the United States was prepared by G. W. Rhodes, Assistant General Superintendent, Burlington & Missouri River Railroad in Nebraska. He quoted the experience of Mr. M. E. Wells, a locomotive-engineer, who had been employed in a complete pooling-system on that line from August, 1893, to November, 1899; with eight-wheel, ten-wheel, mogul and consolidated locomotives, on fast and slow trains, work and local trains; all with crews "first in, first out" on different trains to the best advantage of the service. There were 52 crews, 41 in freight-service and 11 in passenger-service; with an average of 37 locomotives, 30 on freight-trains and 7 on passenger-trains; though, when necessary, the locomotives in one pool were used in the other. There was a saving of 15 locomotives over the old system. All cleaning was done by roundhouse men, and the filling and cleaning of all lights. No headlight-oil or signal-oil was carried on the locomotive. The large tools, for emergencies, were carried in sealed boxes, the small tools in individual boxes which were taken off with the engineer. Lanterns were checked out of the oil-room and individual oil-cans, with engineer's number, were taken to the oil-room, refilled and returned. After the engineer had made his inspection and turned in his report, the roundhouse-inspection began with the hostler; the boiler-maker inspected the boiler, grates, ash-pan and front-end, and the packer inspected the journal-boxes. In August, 1899, with engine-mileage of 299,205 miles, there were but two locomotive-delays from hot boxes; one of twenty-three minutes and the other of thirty. The principal trouble was in "a failure to get work done that is found and reported."

This excellent summary of practical experience with the complete-pooling plan, enforces the conclusion expressed in one of the reports presented at the Washington session of the International Railway Congress, that, "For the complete pooling-system to combine its maximum advantages with its minimum disadvantages requires a special organization, which can not be developed for special cases or for temporary purposes."

A lack of interest in this question was displayed when opinions were sought from the 217 members of the American Railway Association in the United States, Canada and Mexico; from whom only 84 replies were elicited, of which 48 were unfavorable to pooling. The most of these, however, were either from short lines or from lines that were operated in sparsely settled regions. One point alone seemed to be settled. The attempts on long runs with relay-crews had been abandoned. It was found that a relay-locomotive saved more time and gave better service than did a relay-crew.

The report also called attention to the saving in roundhouse accommodation which was afforded by pooling. Roundhouses are considered adequate when they furnish accommodation for one-fourth of the locomotives that are handled at a terminal. At Altoona, on the Pennsylvania Railroad, in 1905, 686 locomotives centered from two divisions. With 52 stalls, 203 locomotives were handled daily with double, triple or multiple crews. Many of them had to stand out of doors in all weather and the need for more accommodation was emphasized as "appalling." Similar conditions prevailed at other terminals.

Experience in North America was summed up as follows:

Why is the question of pooling still an open one? It is not contradicted that pooling increases some items of expense. The main advantage which offsets such increase is the decrease in interest on the capital invested in locomotives. The volume of business and the available supply of motive power are the points to be considered. Under certain conditions of traffic, nearly all the lines pool their locomotives. Notwithstanding the attendant disadvantages, the increased mileage or tonnage shows a decrease in cost per mile and per ton-mile. To keep constantly employed the roundhouse force required for complete pooling, there must be sufficient business to have locomotives constantly arriving that require this care. The additional mileage and tonnage, and the relief from extension of terminal accommodations, make pooling profitable where such conditions prevail.

After a discussion of all the reports presented at the Washington session of the International Railway Congress, the conclusions reached, and unanimously adopted, were expressed as follows:

"In Europe and countries other than North America, the general sentiment is in favor of single crews and unfavorable to complete pooling; except when necessitated by a sudden increase in traffic. For certain services, various combinations of double or of multiple crews are used according to circumstances. In North America, pooling is very general, though seldom used for passenger-service; and the tendency to single crews is manifest. The organization, however, depends largely upon local conditions."

In the extended discussion that followed the submission of the reports on this question, it was evident that the plan of complete pooling had not commended itself to many motive-power officials. As one of them said, "Pooling is unpopular because it requires more supervision and because the enginemen are opposed to changing engines." Perhaps it is for these reasons that the complete pooling-system is contemptuously termed "the chain-gang." Yet a practical man, like Mr. Wells (p. 70), found it to result in a saving of 15 locomotives out of 52, or of about 30 per cent., and with no important disadvantages; the principal trouble being *"a failure to get work done that is found and reported."*

Here seems to be the crux of the complete pooling-system, which was touched upon at the International Railway Congress; that is, it "requires a special organization which can not be developed for special cases or for temporary purposes," and further, that for such an organization to be economically effective, "there must be sufficient business to have locomotives continually arriving that require this care."

The economic efficiency of the several ways of manning a locomotive should be determined by the practical test of ascertaining the relative number of hours on the road between terminals of all locomotives in regular service. On this point there are no official statistics. Many opinions are offered with but few facts. These are from roads on which the pooling system, in some form, is in general use; and they indicate an average of six hours a day for locomotives in freight-service. This is over 50 per cent. better than the general average for the whole country. From an analysis of the report of the Interstate Commerce Commission for 1914, the average hours on the road of locomotives in regular service were as follows:

	Freight	Passenger
Eastern District	3.84	3.63
Southern District	4.64	4.95
Western District	3.30	4.21
United States	3.83	4.07

This statement applies to roads with annual operating revenues above $1,000,000, and excludes an average of 18 per cent. of locomotives not in regular service.[1]

It should be a comparatively easy matter to obtain more definite information of this character from the daily train-sheets and from a classification of all locomotives, as between freight-service and passenger-service. Such reports should show the exact time that each locomotive entered and left the roundhouse, and its time of terminal departures and arrivals. From these facts, the responsibility can be fixed, as between the Motive Power and the Transportation departments, for the disposition made of the idle time of locomotives. There is at present very little information available on this point. If the motive power of our entire railway system is not profitably employed, upon an average, more than four hours out of the twenty-four, surely it is of importance for general managers, and even for presidents, to know how much of the twenty hours of idle time was spent in shops or roundhouse, cold and unmanned, and how much, in simply standing in freight-yards or at terminal stations, wasting fuel with an expensive crew under pay.

Electricity as a Source of Motive Power

The progress made in the substitution of electricity for steam in railway traction gives importance to a discussion of the relative efficiency for this purpose of such a source of power. When the electric current was generated only chemically, as voltaic or galvanic electricity, its energy was insufficient for any purpose requiring the application of power to overcoming resistance of considerable magnitude, and its usefulness in this respect was restricted to the transmission of signals by the electric telegraph. About 1863, electric current was generated mechanically in the dynamo invented by Pacenotti of Pisa, and the way was opened for its development in greater volume and intensity; whereby the application of electricity to useful purposes was immensely extended.

The attention of electricians was first directed to illumination by the arc-light, which was introduced into the streets of New York City in 1882. But illumination by electricity was only made generally available by Edison's invention of the incandescent lamp. Another and widely extended field of electric usefulness was opened up by the invention of the

[1] See Appendix II, Table XV.

telephone. It is worthy of remembrance how the welfare of mankind in the world at large has been advanced by the researches in the field of electricity and by the inventive genius, in this country, of Morse, Edison, Bell and Tesla.

The development of electricity as a source of motive power followed naturally upon its generation by mechanical means, and it soon became extensively used for this purpose in shops and factories as a substitute for steam-driven machinery. The rotary motion imparted directly to the motor from the generator invited its application to the axial rotation of vehicles, which attained commercial success in its substitution for animal power on street-railways in the trolley-system invented by F. J. Sprague.[1]

In a discussion of the further substitution of electricity for steam in railway traction, the first point to be considered is that, save under exceptional conditions, steam and electricity are alike conversions of the energy of heat into motive force. Whether one or the other form of conversion should be chosen, is a matter either of economic or of social efficiency. If electricity be chosen, the power is delivered to the tractors from a central source; if it be steam, the sources of power are in the tractors themselves.

The economy in coal-consumption that can be attained at a central power-station may be illustrated by experience on the lines of the Interborough Rapid Transit Company of New York City. There, it was stated that for every hundred heat-units produced by its original plant, only 7½ units were applied to train-service. Originally, 176,000 tons of coal were consumed in transporting 116,000,000 passengers. In 1913, 332,000,000 passengers were carried on a consumption of 236,000 tons. With the original power-plant, this service would have required 400,000 tons; and as the price of the coal is rated on the base of thermal units, the actual economic value, as well as the mechanical efficiency of the plant, is determined by statistical data of practical importance.

Furthermore, the power-plant of 1901 delivered a kilowatt of power per hour with the use of 17 pounds of steam, but the plant installed in 1911 delivers the same unit of power with 11¼ pounds of steam, which is considered to be the highest rate ever attained for commercial purposes. This improvement is expected to result in an increase of efficiency in train-service of about 42 per cent. Under previous conditions, 300,000,000 gallons of water were used per annum. The water consumption of the new plant is estimated at 200,000,000 gallons, with corresponding economy in coal-consumption.

As already stated, there are exceptional conditions which give economic value to the use of electricity in railroad operation. This is obviously the case where it is practicable to substitute gravitation for combustion

[1] The further invasion of electric traction in the field of railway transportation has been described in Chapter II, pp. 24–32.

in the generation of motive force; as by impounding streams at places where the momentum of a large body of falling water can be applied to the generation of electricity. This is still, however, the conversion of heat into motive force, for it is through evaporation by solar heat that the water has been delivered at the higher level.

The topography of Switzerland has greatly favored the utilization in railway operation of "white coal," as the power so generated has been aptly named.[1] The most important examples of hydro-electric plants in this country are those which obtain their power from Niagara Falls. Water-power has also become of economic value on some of the roads that cross the Rocky Mountains; although on these roads electric tractors are principally employed where good steam-coal and water free from mineral salts are difficult to obtain. But wherever there is an available supply of coal, the saving in the generation of electricity by water-power depends very much upon the necessary investment in engineering works, which varies greatly with topographical conditions. The practical economy resulting from the development of water-power for railway traction is not as great as might be expected theoretically; because of the fluctuation in the amount of power required and because it is not ordinarily possible to locate the hydro-electric power-station at traffic-centers, or even on the line of railway. The place whence water-power is obtained is fixed by the physical environment, and the electric current must often be transmitted for long distances to the points at which it is to be applied to traction. Great expense is involved in establishing and utilizing a hydro-electric plant, and then it may become unreliable because of drought, floods or extreme cold, or from unforeseen catastrophes.

Transmission of Electric Power

In order to follow the development of electric traction, it is well to have some notion of the manner in which electro-magnetic force is imparted to the tractor. In the earlier dynamo, the rotor, revolving continuously in one direction, produced a tension or pressure in the flow of current through the conductor designated as a "continuous" or "direct" current. In the alternating dynamo, for which we are largely indebted to Tesla, there is an alternating pressure or reversal of potential in the current, increasing with the rapidity of the alternations, and designated as the "single-phase alternating current." An impulse may be imparted from another electromotive source, so timed that its effects will alternate with the primary pulsations, like the crest of one wave coinciding with the trough of another, and the tension or pressure is thus correspondingly augmented. Similar impulses may be derived from other independent sources, and so are pro-

[1] In 1908 the total available water-power in Switzerland was estimated at 750,000 horse-power, of which one-fourth had been utilized.

duced two-phase, three-phase or polyphase currents. Without going at present into further particulars, it may be stated that by certain ingenious arrangements in the apparatus, means have been devised for transforming these currents into continuous or direct currents and, in doing so, to greatly reduce the voltage.[1]

The use of electricity as a substitute for steam in railway operation, is still in an experimental stage. The preferable forms of current and of conductors have not yet been definitely established. In the early development of electric traction, the continuous or direct current was transmitted at the voltage generated at the power-plant, and was applied directly to the motors. Experience, however, proved that continuous current could not be economically generated for long-distance distribution and for heavy traffic. To meet these requirements, this system has been modified by the generation of alternating current, transmitted at high voltage and transformed to lower voltage at substations and into continuous current. Up to 1907, this was the system employed in heavy traction.[2]

The Erie Railroad was the first steam-road to use power from Niagara Falls. It was applied on an electrically operated line of 33½ miles branching off from Rochester, 77 miles distant from the Falls. The power is generated as single-phase current at 66,000 volts, transformed to three-phase at 11,000 volts at substations and, at this voltage, supplied to feeders for use on a trolley-system.

In 1907, the straight alternating-current system came into use on the New York, New Haven & Hartford Railroad. In this system, the current is transmitted as single-phase at high voltage and then transformed to lower voltage in alternating-current motors on the electric tractors. The New York, Westchester & Boston Railroad is operated on the New Haven system in its latest development, with 11,000 volts on multiple-unit motor-cars.[3]

The polyphase alternating-current system, or three-phase system, was inaugurated in America in 1909 at the Cascade Tunnel on the Great Northern Railway. This is a three-phase alternating current fed into line-conductors at high voltage and utilized in three-phase motors. A modification of this system has been applied in the recent electrification of the "Elkhorn Grade" on the Norfolk & Western Railway. Here, single-phase current at 11,000 volts is delivered to the tractors and there

[1] The Volt is a measure of electric pressure analogous to the measure of steam-pressure by the number of pounds per square-inch.

[2] High-voltage current, exceeding 100,000 volts, is transmitted over 200 miles. For transmission up to 20 miles, 11,000 volts is the usual standard. For longer distances, 22,000, 33,000, 66,000 and even higher voltage is applied. Such transmission was made possible by means of devices invented about 1890 by William Stanley, an American engineer.

[3] In the multiple-unit system, each car is supplied with its own motors, which can be so connected that all the motors in a train may be operated collectively from a single control.

transformed by a "phase-converter" into three-phase current at 750 volts for the motors.[1]

For long trunk-line work, and for the average density of traffic on American railways, the first cost of the alternating current, transformed into direct or continuous current, known as the "A. C.–D. C." system, would be prohibitory. The only possible alternative would be the "single-phase system" which, as yet, is also too expensive. Still, in the opinion of Mr. W. S. Murray, Chief Electrical Engineer of the New York, New Haven & Hartford Railroad, the single-phase system is the most economical for trunk-line purposes. He states that the economic transmission of power is conserved by the agency of high voltage. It is considered by practical men that 1500 volts is the limit of direct-current trolley-potential, or power of doing work, and there is great difficulty in collecting current from an overhead wire, at this voltage, for operating an 800-ton train.

On the contrary, in a paper read before the Canadian Society of Civil Engineers in December, 1913, by A. H. Armstrong, a well-known electrical engineer, it was stated that the interurban railroad companies which had adopted the single-phase commutating motors were changing to continuous current as fast as financial conditions would permit.[2] The single-phase system had been introduced to obtain a higher voltage than the commercial 600 volts. Attention was then given to applying higher voltage to the continuous-current motors with such success that a voltage of 1200 and 1500 volts is being quite generally applied to such motors.[3] In the electrification of steam-roads, there is no important installation of the single-phase system except on the New Haven lines. Under exceptional conditions, the three-phase system has been adopted on the Chicago, Milwaukee & St. Paul Railway, and the modification of that system, known as the "split-phase system," on the suburban lines of the Pennsylvania Railroad at Philadelphia, and on the Norfolk & Western Railway.

In the early days of single-phase traction, trouble was experienced from disturbance of telegraph, telephone and signaling apparatus, which was for the most part remedied by the use of the metallic return, and the trouble has nearly ceased with improvements in the motors. Yet there is still danger that adjacent continuous-current conductors may, by electrostatic induction, acquire a very high potential. This may be remedied by short-circuiting the two wires of each circuit at frequent intervals with a discharge-coil of very high inductance, which carries the static charge to earth. Placing the continuous-current conductors underground is an

[1] See page 84.

[2] In the commutating motor, an alternating current can be transformed into a continuous current or vice-versa.

[3] On the Butte, Anaconda & Pacific Railway, a voltage of 2400 volts is so employed.

effective method of protection, but the cost of this is over $5000 per mile.[1]

The difference of opinion as to the relative merits of the several forms of current for electric traction prevails also with reference to the means for conducting the current to the motors, whether overhead or by "third-rail." Several varieties of these two general forms are still under costly experiment on some of our principal lines.

The third-rail conductor for continuous current had its origin in the conduit that replaced the forest of poles and the maze of telegraph, telephone and trolley wires that disfigured the streets in our larger cities. This conduit, it may be mentioned, had itself been borrowed from the cable-railways that were first put in operation in San Francisco. As the early street-trackage was extended and the flow of continuous current diminished with the increasing distance from the power-plant, additional current was fed into the trolley-wire from a separate conductor, at intervals, through "boosters."[2]

The greater volume of direct current absorbed in traction for heavy railway traffic requires a conductor of far greater cross-section than a trolley-wire. Resort was therefore had to the conduit-rail, placed on the outside of the track-rail, as the "third-rail system." In this system, the contact-shoe completes the connection with the motor in place of the trolley in the overhead system. Here, again, the difficulty in maintaining the volume of direct current necessary for heavy traffic over long distances led to the introduction of the alternating current, distributed along the line in a separate conductor and transformed at intermediate substations, where it is fed into the third-rail as the current is fed into the trolley-wire through boosters.

The position and height of the third-rail must be rigidly maintained and the margin of permissible variation is small. Its continuity is broken at switches and crossings by frequent transference of the conductor to the opposite side of the track or overhead. The position and height of an overhead wire may vary within vertical and horizontal limits of eight and four feet respectively, without losing contact with the pantograph-bows, which have replaced the trolley-wheel on the metallic overhead circuit.

In the New York Subway, current is fed into the third-rail every mile, and the conductor has to be of large surface to carry the great volume of low-pressure current. The Subway runs more trains in an hour than all the through trains in a day between New York and Chicago, and has its

[1] Induction is the influence exerted by an electric current, or by an electrically charged substance, upon a neighboring conductor or electrically sympathetic substance, without any direct connection between them. A discharge-coil, or "choking coil," absorbs such induction and discharges it directly to earth.

[2] A booster is an auxiliary dynamo placed in the main feeding-conductor, by which additional power is supplied to the trolley-wire, as it is drawn upon by the passing motor-cars.

whole equipment virtually in continual service. On no railroad line are there more than a dozen through trains between New York and Chicago, and the electric generating capacity on such a line would be required only occasionally at its maximum.

As the capacity in an electric conductor is in proportion to its surface, the third-rail provides the means for the sparkless collection of current at low voltage in large quantities, but it requires a heavy investment in copper conductors, in substations and in frequent power-plants.[1] The same energy can be supplied through a small wire by a high-tension current. On the New York, New Haven & Hartford Railroad, the alternating current is fed into the conductors at only one point between Woodlawn and New Haven. From Woodlawn to Grand Central Station, the New York Central continuous current is used.

The improvements effected on the Pennsylvania Railroad made it technically possible to transmit large quantities of low-tension continuous current through third-rail conductors. With 600 volts in the line, a speed of 59 miles an hour was attained on a level, with trains weighing 550 tons and the tractor developing 2000 horse-power. To prevent the voltage dropping with the large volume of current, a third-rail is required of increased section, which on the Pennsylvania Railroad weighs 150 pounds to the yard.

The first success with high-voltage motors was obtained with the three-phase current, but better results have been secured with the single-phase alternating-current motor. Yet objections have become so apparent that, on the Washington, Baltimore & Annapolis line, return has been made to continuous current with voltage increased to 1200 and 2000 volts. It was also found that a motor-car equipped for the alternating current weighed 60 tons against 40 tons for the continuous current.

The relative advantages and disadvantages of the continuous and of the alternating current may be summed up as follows: The continuous current has the advantages of good regulation of motors, simple construction, cheaper car-equipment, elimination of transformers and no disturbance of telegraph, telephone or signaling apparatus. It has the disadvantages due to limitation of voltage and to restriction of the distance in which it is effective from a single power-plant, even with frequent substations. The alternating current has the advantage of a greater radius of action at high-tension from a single power-plant, which may be transformed at substations into continuous current or used directly for traction by intermediate reduction of voltage on the tractors. But the car-equipment is much heavier, with greater initial outlay for overhead conductors and greater working-expense. It also necessitates special protection for telegraph and signaling apparatus. The continuous-current system, up

[1] Substations can not be more than eight miles apart, as this is the maximum distance for economy in copper feeding-lines.

to 750 volts, has long been standardized and is generally adopted for urban and for suburban lines. The three-phase system has been fairly standardized, but the single-phase system is still in process of development.

Electric traction with continuous current was originally restricted to multiple-unit motors. The maximum size of motors was practically 200 horse-power for each truck of a motor-car at a one-hour rating which, with direct current of 600 volts and forced ventilation gave a continuous capacity of 140 horse-power.[1]

This is the usual practice with single-reduction geared motors. With the multiple-unit system, there is virtually no limit to the motive power which can be applied to a train, other than the number of axles in it. A New York Subway train of eight cars is usually made up with five motor-cars each having two 200 horse-power motors with which a speed of 100 miles an hour can be attained. With 2000 horse-power, the train is under full headway in three times its length, and the prescribed speed is then maintained with 300 horse-power. With continuous current, motors may be coupled in series, working up to 750 volts, or from 900 volts upward with reversing-pole motors in parallel connection.[2]

Efforts to advance the efficiency of electric traction for railway purposes have been directed mainly to operating at higher voltage, either by increasing the heating-capacity of continuous-current motors or by designing motors to be actuated by alternating current, in order to avoid transforming the current at substations. On the suburban lines in Melbourne, Australia, it has been decided to use three-phase current at 20,000 volts, transformed at substations into 1500-volt continuous current, using the running-rails for return. It is proposed to electrify 87 miles of line, with 288 miles of track, from a centrally situated plant.

Electric Tractor Design

The electric motor can exert its full power at starting. But as this effort is continued, it is accompanied by an increase of internal heat in the motor which tends to destroy the insulation, if it exceeds a critical temperature. The electric energy must therefore be gradually diminished to prevent overheating. Electric motors are, for this reason, rated at a starting-effort, at a one-hour rating and at a continuous rating. The liability to overheating may be diminished by fireproof insulation and by artificial ventilation, with accompanying capacity for operation at increased voltage.

[1] The capacity of a motor for high voltage is limited by the resistance which the material in its construction offers to the pressure of the current. By this resistance, the flow of the current is checked and becomes transformed into molecular heat, which may reach an intensity destructive of the motor-apparatus. This defect is somewhat minimized by artificial ventilation of the motor.

[2] In series connection, the current passes successively from first to last through a series of motors. In parallel connection, the current is divided between the motors.

In the substitution of electricity as a motive force on steam-driven roads, under ordinary operating conditions, it became necessary to separate the motor from the carriage as an independent tractor. In taking this step, it was assumed that it was a simple matter to apply the rotary motion and uniform torque, or twisting effect, of the motor directly to the axles of a tractor. This would obviate the objectionable features of unbalanced reciprocal weights and the dead points in the conversion of reciprocal motion in the steam-cylinder into the circular motion of the driving-wheels.

The tractors originally designed for the Grand Central Terminal system were magnified motor-cars, operated by continuous current at low voltage, fed through a third-rail to motors acting directly on each axle, and intended to deliver a moderate tractive effort at high speed. In 1909, one of these tractors, weighing 102 tons, exerted a tractive effort of 7100 pounds continuously at 56 miles an hour and 20,600 pounds at a one-hour rating. The four motors could, therefore, give an output of 2200 horse-power for one hour without overheating. In 1913, a tractor designed for regular passenger-service weighed 100 tons, all on motor-driven axles. It developed normally 1400 horse-power, with capacity of 5000 horse-power for short periods, and with tractive power sufficient to take a train weighing 1000 tons at a speed of 60 miles an hour. This design was subsequently modified to carry part of the weight on leading and trailing trucks. In a tractor placed in service in December, 1914, weighing 132 tons, motors were also placed on the axles of these trucks. The tractors of this type can exert a tractive effort of 14,000 pounds at 53½ miles an hour, developing 2600 horse-power at a one-hour rating and 2000 horse-power at a continuous rating. Current is collected by eight under-running third-rail shoes, or by two overhead trolleys when at gaps in the third-rail. The trolleys are of the pantograph-type and are held in a raised position by the pressure of the motorman's foot upon a pneumatically operated valve.

With experience, it was found that when the machinery, in an electric tractor for heavy traffic, is centered around the driving-axles and the weight concentrated below the top of the wheels, the effect is more destructive to the track than with a steam-locomotive. The motors were then placed upon the frame of the tractor, but still operated directly on each driving-axle, as in the New Haven tractors. The first of these tractors was placed on the line in March, 1907, weighing 78 tons. On February 4, 1910, a tractor was tested in freight-service on that line which weighed 175 tons, with estimated handling-capacity of 2000 tons at 45 miles an hour. It handled 30 loaded cars and a heavy locomotive at a speed of 50 miles an hour, making 18 miles in 27 minutes on a track slippery from freezing drizzle.

The design of the New Haven tractor is complicated and its weight is increased by the necessity for third-rail operation on the New York

Central tracks, and also for transforming the alternating current on the tractor. It is mounted on four 62-inch driving-wheels and two trucks. On each end of the driving-axle, in the hub of the wheel, are seven circular pockets containing helical springs for assisting in carrying the weight of the motors and for transmitting the torque from the armature. Into each of these pockets projects one of the hollow pins on the end of the armature shaft. The springs fit into tubes, and these, with the springs, may be taken out from the pockets, which are lubricated. Though capable of sustaining the whole weight of the motors, these springs are normally used solely for transmitting the torque. The weight of the motors is carried on a steel frame, independent of the trucks and pivoted from the journal-boxes of the driving-axles. In this frame, the motors are suspended by springs, so that the swaying of the tractor has no effect upon them. For continuous-current work, the two motors are connected in series in starting, and in parallel at full speed. For alternating-current work, they are joined in parallel at all times. The tractor is controlled from either end by a lever like the throttle-lever, and any number of tractors may be operated from one controller. Two pantograph-bows collect current from the overhead wire. These collectors are pressed against the wires by springs and are lowered by compressed air. For use on the New York Central tracks, a lower overhead pantograph-trolley is required and also third-rail contact-shoes, two on each side of each truck, which are designed for both over-running and for under-running the third-rails. The shoes are lifted out of the way by an automatically operating device when alternating current is used.

The Pennsylvania Railroad management, with its usual thoroughness, instituted an extensive series of experiments, in which it was found that, at speeds above 40 miles an hour, the steadiest riding was attained with a high center of gravity; that the nearer the steam-locomotive design was approached in wheel-arrangement, distribution of weight, height of center of gravity and ratio of spring-borne to under-spring weight, the less was the side-pressure registered on the rail-head. In addition to excessive side-pressure, due to the oscillation of a low center of gravity, abnormal track effects were caused by the vertical pounding due to a large non-spring-borne motor-weight with imperfect spring-cushion. The remedy for these defects was found in a radical departure from the original design for an electric tractor as to running-gear and motor-drive. It was in 1909 that the Pennsylvania Railroad Company adopted a double tractor, the halves being permanently connected with the wheel-arrangement of two locomotives of the "American" type (4–4–0), set back to back. Each tractor has a gearless motor on top of the frames, driving through connecting-rods to a jack-shaft and thence by main and parallel rods to the wheels. These tractors are virtually on the multiple-unit system, as the complete tractor consists of two separate sections of 1000 horse-power each, and can be controlled in couples. The motors make 264 revolutions per minute at 60 miles an hour, and weigh 42,000 pounds each. A double-header of 4000 total horse-power, weighing 166 tons, can start a freight-train a mile and a half in length, and can make 75 miles an hour with a train of ten Pullman cars. These tractors were compared with the standard passenger-locomotives developing 1600 horse-power and weighing 90 tons, and costing $22,000, while the electric tractors were estimated at $50,000 each.[1]

Recent Installations of Electric Traction

In the more recent examples of the electrification of steam-roads with heavy traffic, preference has been shown for single-phase current in an overhead conductor, transformed for delivery as a three-phase current into synchronous motors.[2] This "polyphase system" has, however, been adopted in each case under exceptional conditions, and is open to the objection that the train-service is restricted normally to predetermined rates of speed.

The suburban lines of the Pennsylvania Railroad out of Philadelphia have been electrified since September, 1915, for 20 miles to Paoli, with 93 miles of track. The current is obtained from a power-company; single-phase at 13,200 volts from one phase of its three-phase generating system. It is then stepped up to 44,000 volts for transmission, and reduced again at four substations to 11,000 volts for delivery to the trolley-circuits. From these it is fed to two single-phase, air-cooled repulsion-motors, or "split-phase" motors, of 225 horse-power on each car, connected in series at 2200 volts. In these motors, invented by Professor Elihu Thomson, the current in the generator actuates the motor through induction only, by the repulsive effect of electro-magnetism, as evinced in the action of the magnetic needle. By an ingenious arrangement of the induction-apparatus, a single-phase, high-tension current, as thus induced, is transformed into several continuous currents at lower tension. There are no rheostats, contactors or similar gear. The regulation is effected by mechanical

[1] In anticipation of the application of electric traction on that portion of the main line of the Pennsylvania Railroad traversing the summit of the Alleghany Mountains between Altoona and Conemaugh, 35 miles, an electric tractor has been designed to operate on 11,000-volt, single-phase, 25-cycle current from an overhead trolley. The single-phase is converted into three-phase current for use in motors, four in number, rated at 1200 horse-power each. Two motors are mounted on each truck-frame, geared to a jack-shaft impelling driving-wheels through connecting-rods. Springs in the gears of the jack-shafts are adjusted to give the effect of solid gears up to 25 per cent. of the weight on the driving-wheels. The draft-strains are carried through the trucks and articulation in a direct plane 34½ inches above the rail, to relieve the cab from such strains.

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[2] In a synchronous motor, the speed of the motor is regulated by that of the dynamo or generator at a predetermined rate which can not be exceeded, but may be reduced by the intervention of resistance-coils, or rheostats, though with accompanying waste of current.

transmission to the brushes of the motor, controlled by the movement of a hand-wheel in the driver's cab.

An interesting example of the three-phase system for heavy traffic has recently been installed on the Norfolk & Western Railway, upon one of its most difficult operating divisions with heavy grades, and on which there is originated a large volume of coal-traffic. This division of 29 miles is double-track, except for 3100 feet through Elkhorn Tunnel, with 4 miles of passing-sidings, 7 miles of branch-lines, 5½ miles of mine-sidings and 21 miles of yard-track in five yards; making a total of about 95 miles of track. The principal grades against east-bound traffic are in two stretches of 1.5 per cent. for about five miles each, one of 2 per cent. for four miles, one for nine and a half miles of 0.4 per cent., and one of three miles of 1.25 per cent. The Elkhorn Tunnel is on a 1.5 per cent. grade, ascending eastward, and is ventilated by the method of forced ventilation devised by Mr. Churchill, Chief Engineer of the line. Sixty per cent. of this division is on curves, with maximum curvature of 12° on the main line and of 16° on sidings.

The normal service consists in collecting loaded cars and trains bound eastward, and in delivering return-empties. The coal-traffic had doubled in volume in four years and the average daily requirement had reached 65,000 tons. The maximum trains of 3250 tons each were handled by two Mallet locomotives, with a Mallet pusher up the heavier grades. These locomotives, with adhesive weight of 370,000 pounds and total weight of 540,000 pounds, had a tractive power of 85,000 pounds. The normal speed was seven to eight miles an hour on the grades, and six miles through the Elkhorn Tunnel, with frequent congestion and delay.

In the substitution of electric traction, it was decided to use repulsion induction-motors, or synchronous "split-phase" motors, with two rates of speed, respectively at 14 and 28 miles an hour, and the tractors were specially designed to meet this requirement. The current was generated as single-phase of 11,000 volts at a central station and was stepped up to 44,000 volts for transmission to four substations, where static transformers lowered the voltage again to 11,000 volts for delivery to the overhead conductor. On the tractors, this single-phase current was converted into a three-phase current at 750 volts for delivery to the motors.

The trains when loaded are half a mile in length, and three-quarters of a mile when empty. To start a train, it is necessary that the head and rear tractors should exert their full power simultaneously. The motors therefore permit full-load current to be applied for five minutes before starting. This type of motor has the valuable characteristic of "dynamic" or regenerative braking, without the use of air, and with consequent saving of wear to the brake-equipment. When "drifting" on long grades, at a slightly higher speed than the predetermined rating, the static energy in the descending train may be utilized as a source of power in energizing a reverse action in the motor. The motor then acts as a generator of electricity, which is transformed in the apparatus into single-phase current and returned into the overhead circuit. At a rate of speed four per cent. above the predetermined synchronous rate, the motor will deliver its full-load rating back into the line. The continuous reaction of the motor-torque resists the accelerating effect of gravitation and preserves a uniform rate of speed during the descent. These tractors are technically termed "articulated geared side-rod," being operated in this respect like the Mallet locomotive, as a coupled pair, and with similar wheel-arrangement (2–4–4–2, 2–4–4–2).[1]

The most ambitious project yet undertaken in the substitution of electric traction for steam has been installed on the extension of the Chicago, Milwaukee & St. Paul Railway to the Pacific Coast, mentioned in the previous chapter. In passing over the Great Continental Divide, from Harlowton, Montana, to Avery, 440 miles, the line crosses the Belt Mountains at an elevation of 5768 feet, the main Rocky Mountain Range at 6350 feet, the Bitter Root Mountains at 4200 feet and the Cascade Mountains at 3010 feet, with several tunnels, including one of 9000 feet. The maximum grade westward is 2 per cent. for 20.8 miles; and east-bound, 1.7 per cent. for 24 miles. The line ascends the eastern slope of the Belt Mountains on a continuous one per cent. grade for 44 miles. The difficulty in procuring suitable feed-water and cheap coal, and the proximity of an ample supply of electric current from a hydro-electric company, induced the railway company to operate this entire district of 440 miles, covering 650 miles of track, by electric traction only; an enterprise of greater magnitude in this respect than had before been undertaken, and at an estimated cost of $12,000,000. A division of 115 miles was put in operation on December 5, 1915, and another division of 112 miles was to be so operated in May, 1916.

Power is delivered from the hydro-electric plant through three lines of copper-tubing, which is an important improvement over wire conductors, since the ratio of weight to transmitting surface is thereby greatly reduced. Three-phase current at 100,000 volts is distributed to fourteen substations, where it is transformed to 3000 volts — the highest continuous current used anywhere for electric traction. This high potential for continuous current was adopted after experience for a year and a half on the Butte, Anaconda & Pacific Railway with 2400-volt continuous current, fed into 1200-volt motors in series. In this installation, two 60-cycle, 1500-volt synchronous motors are connected permanently in series.[2]

The motors are geared to the driving-axles of the tractor, a coupled pair; each half with eight drivers and a four-wheel truck. Each tractor weighs 260 tons, is 112 feet in length, costs $112,000, and has a tractive

[1] For details of electric tractors and traffic performance, see Appendix II, Tables XVI and XVII.

[2] In a 60-cycle motor, the current changes direction 60 times a second.

power of 85,000 pounds, against 75,000 pounds in the Mallet locomotive which it replaces. The tractors for passenger-service are designed to haul an 800-ton train at 60 miles an hour on a level, or at 30 miles an hour up a one per cent. grade. The freight-tractors can take a 2500-ton trailing-load up one per cent. grades at 16 miles an hour, or up a two per cent. grade assisted by a pushing tractor. At the summit, the pusher is taken to the head of the train and the motors in both tractors are utilized in retarding speed on the descent by regenerative braking, and without using the air-brakes. By this means, from twenty-five to fifty per cent. of power is recovered and turned back into the trolley-wire.[1]

The most obvious objections to three-phase tractors are the complication of a double overhead wire, the danger that the motors do not share the load fairly, and the inability to run at intermediate speeds without rheostatic waste, or to run at higher than synchronous speed to make up lost time. The objections that the motors will not share the load equally is theoretically sound. In order that they should do so, their speeds must be the same; in practice, this difficulty, arising from slight differences in the size of the driving-wheels, is counteracted by the slip-adjustment of the motors. But a train pulled by a series-motor, whether with continuous or alternating current, runs slower up-grade or if abnormally heavy, while, with the three-phase motor, the speed up-grade may be practically the same as on a level. Also, the feature of regenerative braking, peculiar to the synchronous motor, is a valuable adjunct to train-service on long and heavy grades.

Comparative Economy of Steam and Electric Traction

Much remains to be done as to design and performance before the electric tractor reaches the approximate perfection that has been attained with the steam-locomotive. The steam-locomotive is a primary source of power; the electric tractor is a secondary source, whose efficiency depends upon its continuous connection with the power-station. By the temporary separation of the generator from the motor, by means of storage-batteries, a quasi-independent electric tractor has been devised by Beach and Edison for street-railway service. It was experimentally tested, in 1910, between New York and Boston, via Albany, but it does not meet the requirements for steam-railway operation.[2]

As a mobile tractor, the theoretical advantage of the continuous application of power by rotary motion has been discounted in the electric

[1] For additional data see Appendix II, Table XVII.

[2] On Sept. 26, 1912, it was announced that a train operated by storage-batteries under multiple-unit control, built for the United Railways of Cuba, had been tested on the Long Island Railroad. The train was composed of three cars, each with four 200-volt motors and 216-cell Edison batteries, recharged from third rail, with mileage-capacity of 60 to 100 miles from seven hours' charging.

tractor operating through connecting-rods and cranks. The capital invested in electric traction becomes proportionately greater with fewer motors, and that consideration alone points to its restriction to frequent train-service. Nor does the opportunity for economy in fuel-consumption at central power-stations outweigh the merits of the independent steam-tractor. The saving from this cause must cover interest on the investment in the entire electric plant and for its maintenance, as well as for covering the losses involved in converting mechanical power into electric energy at the power-station, conducting the current to the tractor and there re-converting it into mechanical power. The cost of protecting telegraph and telephone lines and signaling apparatus from induced currents or from electrolysis is also to be considered. While steam-locomotives may be idle for much of the time, it is not possible to interrupt the running of the power-station, though the loads may be reduced, for the whole conducting system must be kept supplied with current.

In a paper read in 1914 before the British Association for the Advancement of Science, Professor W. E. Dalley asserted that as yet there was no appreciable difference in the efficiency of the electric tractor, as compared with the locomotive, for the expenditure of an equal number of heat-units. After allowing for all losses in both cases, only about four per cent. of the total energy of the fuel consumed appears as mechanical power at the driving-wheels of either tractor. The electric tractor can, for a brief period, exert over double its normal power — a quality that the locomotive does not possess, and one which is advantageous on lines with frequent short and heavy grades, and it can also attain a higher speed more quickly from a state of rest under similar conditions.

The electric motor-car can develop a speed of 30 miles an hour in 30 seconds, using the whole weight of the train for adhesion, and giving it superiority for suburban traffic with frequent stops; but this advantage is minimized when trailers are used, and, with the adoption of the locomotive-wheel arrangement, it entirely disappears. The motor-car wastes no current when idle, while the locomotive must be kept under steam to be ready when required. Electric tractors do not have to be turned, and their superiority for use in long tunnels is manifest, if only as a matter of social efficiency. The multiple-unit motor-car train can be economically modified to suit fluctuations in traffic. There are but few locomotives that can generate sufficient steam to furnish full-cylinder tractive power at speeds in excess of twelve miles an hour. Increase of speed must be obtained by sacrifice of tonnage, and to this fact is due the high cost of fast-freight service. With the electric tractor, however, high speed may be attained without corresponding loss of tonnage, since, with a relatively unlimited source of power at command, the maximum drawbar-pull may be maintained at all speeds. But, at present, for general railway service at speeds not exceeding 60 miles an hour, there is, after all, no more economical tractor than the steam-locomotive. In a comparison of the efficiency of these two forms of motive power, it is also to be considered that, where the power is derived solely from a central source, any interruption in the output affects every tractor dependent upon it, and a general disturbance to the service ensues; while any interruption to the operation of an independent tractor affects its immediate environment only. The advantage of the steam-locomotive in this respect can only be neutralized by the successful operation of an electric tractor which is similarly self-contained, and that is as yet a desideratum.

American and Foreign Methods of Electric Traction

In this country, almost all trunk-line electrification has been on the continuous or "direct current" system; while in Continental Europe, it has been principally on the "three-phase alternating current" system. Apart from other considerations, this difference of opinion upon the fundamental problem of railway electrification has arisen from differences in the respective social environments. The extensive area covered by our railway system under similar conditions as to government, language and social habits and customs, has enforced uniformity in railway operation in matters in which an interchange of equipment or an observation of one and the same set of traffic-regulations is necessary for a cheap and convenient public service. The consequence is a continuing tendency to recognize the advantage and necessity of uniform methods and appliances in railway operation, and the establishment and maintenance of standards.

It is the existence of this tendency that has led to the manufacture of railway equipment and appliances, as commercial undertakings, on a larger scale than elsewhere. This has been particularly the case with electric equipment of all kinds. With the advent of steam-railway electrification, the great industrial corporations entered energetically into this field, while it was yet in its experimental stages. The initial work was taken out of the hands of individuals and concentrated under their own direction and in accordance with their own standards. As these were derived from street-railway experience, it was to be expected that street-railway electric practice should at first predominate, as was the case with the adoption of the "direct-current" system.

Electric traction was developed in Great Britain under the direction of these same great manufacturing concerns but, in Continental Europe, the social environment gave prominence to the views of technical experts, who were not so much affected by commercial considerations as by theoretical training. Their respective fields of operation being restricted by national boundaries, there were many centers of development and much diversity in methods and appliances, by which the progress of railway electrification has been hindered rather than advanced. State-control has enabled state officials to exercise a benumbing authority in every stage of its development. In this country, the advocates of the alternating-current systems had to contend with the influence of the corporations interested in the development of electric traction on commercial lines. In Continental Europe, and particularly where German influence was authoritative, the opinions of official electricians have prevailed.

The "three-phase alternating current" system was established in Germany by agreement between the several state governments. In this country, the "direct-current" system was introduced by the extension of street-railway experience under the influence of corporations engaged in the manufacture of direct-current equipment. Then the great railway corporations intervened and, after extended and expensive experiments, took in hand the designing of electric tractors for trunk-line traffic which were far more efficient than any that have been originated by the official electricians of the European states who, in fact, have had to look to this country for a lead in steam-railway electrification.[1]

Different Applications of Electric Traction. Gasoline Motors

At present, electrification of railways should be considered as it affects

I. City rapid-transit lines.
II. Quick-transit suburban lines.
III. Lines directly connecting large cities.
IV. Trunk-lines with long-distance traffic.

The principal examples in the first category are the municipal systems of New York, London and Paris, in which the "direct current" system has proved its efficiency. The extension of the city rapid-transit lines into quick-transit suburban lines has induced the use in common of motor-car trains on the multiple-unit system, and here experience seems to indicate a combination of the "three-phase" system with its transformation into continuous current as fed into the motors.

The electrification of lines extending beyond the suburban zone has been accomplished hitherto with the direct-current system at low voltage, because it is also a further extension of the city street-car lines with which it connects; and here, too, the three-phase current, transformed at sub-stations into direct current, seems to be preferable. But the electrification of interurban steam-railroads, without street-car connections, is another matter, since it involves the handling of freight as well as passengers, and the operation of freight-terminals and intermediate sidings to industrial enterprises. With the growth of traffic on such lines, there is a tendency to differentiate the methods of electric traction for passenger-service and for

[1] Much information about eléctric traction has been obtained from the Bulletins of the International Railway Congress, and especially from the Report on American practice by George Gibbs, Chief Engineer of Electric Traction on the Pennsylvania Railroad lines, presented at the meeting in Berne, in 1910. Valuable assistance has also been kindly given by railroad officials engaged in this branch of engineering.

freight-service, preserving the multiple-unit system, with trailers, for the passenger-service, and gradually introducing tractors of a different design for the freight-service.

At the time that it was proposed to substitute electric traction for steam on the Grand Central Division of the New York Central lines, there had been no experience in its application to high-speed trunk-line passenger-traffic. The tractors designed on the lines of the motor-car, developed the unsuitability for such traffic of motors geared directly to the driving-axles. Next, the application of electric traction to the entire long-distance traffic of a trunk-line was undertaken by the New York, New Haven & Hartford Railroad Company. Here, the tractor was differentiated from the motor-car, with single-phase current transformed on the tractor and fed into the motor at higher voltage than had been before attempted in electric traction. This led to a departure from the third-rail conductor, and a return to the overhead wire in a very expensive form, which compelled an entire rearrangement of adjacent telegraph and telephone lines and of the railway signaling-apparatus.[1] The design of these tractors was complicated by the necessity for providing direct-current operation in the Grand Central Zone. Although this installation has proved that the entire long-distance traffic of a trunk-line can be successfully conducted on the single-phase, high-tension system, yet the cost of its application between New York and New Haven was so enormous that other railway managements have been deterred from adopting it in its entirety.

The character of the electrification of the Pennsylvania lines within its Manhattan Terminal zone was determined chiefly by the operation of the extensive suburban traffic of Long Island, on the direct-current, multiple-unit system. For its high-speed trunk-line passenger-traffic, however, a notable departure was made from previous practice as to independent tractors, by transforming the rotary motion into reciprocal motion in its transmission to the driving-wheels. This change affects its through passenger-traffic for only a short distance out of New York, and has not been imitated elsewhere, except on the Norfolk & Western Railway for coal-traffic.

The principal substitution of electric traction for steam, has been compelled by considerations of social efficiency, — the necessity for providing frequent and speedy passenger-service for short distances. Incidentally, it has been enforced as a police measure, to free a populous region from the nuisances of steam and smoke. Its claim to economic efficiency in this field is limited, at present, to the relief which it affords in the operation of passenger-terminals already crowded to their capacity. Outside of such terminal zones, and such suburban traffic, electric traction had been substituted for steam only in badly-ventilated tunnels.

But with the introduction of the induction-motor, a new field was

[1] The peculiar features of electric track and overhead construction are described in Chapter V, Part II, pp. 253–256.

opened for electric traction in the conduct of heavy freight-traffic. The importance of this recent development is apparent in the description already given of its installation on the Norfolk & Western Railway and on the Chicago, Milwaukee & St. Paul Railway. In the latter instance, an example is furnished of complete electric traction on a trunk-line of 440 miles, operated under peculiarly difficult conditions. If its promise of economic efficiency should be there fulfilled, the induction-motor, with high-tension alternating current, would seem to be the system best suited for heavy traffic, where high speed is not required.

On lines not exceeding a hundred miles in length, through a densely populated region and between large cities, as between New York and Philadelphia, it might be found advisable to conduct the freight-traffic by steam and the passenger-traffic by electricity; but on separate tracks. As to long-distance freight-traffic and passenger-traffic, on trunk-lines, there is a growing conviction that the third-rail conductor and continuous current are not preferable to steam for cheap operation; that the New Haven installation is too expensive as a capital investment, and that the three-phase system is efficient only under exceptional conditions.

It would seem from the standpoint of motive-power efficiency, as well as from that of railway efficiency in general, that steam will continue to be the cheapest motive force for ordinary railway purposes until some hitherto undeveloped form of electric traction has been discovered, requiring less capital investment and cheaper cost of maintenance. Until then, steam-locomotives will continue to haul heavy trains for long distances over ordinary grades, in regions lacking abundant and available water-power but well provided with good fuel. Eventually, American ingenuity may solve the problems that must precede the electrification of our railway system so as to combine theoretical efficiency with commercial economy, and establish uniform standards of method and appliances. Only when this has been accomplished can there be a just comparison of the respective fields of steam-traction and electric traction.

As the use of electricity in street-railway operation led to its introduction on steam-railroads, so the remarkable development in the application of gasoline in explosive engines for highway-traffic has induced some experiments in its use in "rail motor-cars." In 1904, the Union Pacific Railroad Company placed such motors on branch-lines, where their apparently low operating cost might warrant more frequent passenger-service in thinly populated districts over roads with heavy freight-traffic. In 1911, that company had 113 of these cars in service. One built in 1915 is described as developing 300 horse-power in a seventy-foot car carrying mail, baggage and express, and making 55 miles an hour with a standard steel passenger-car as a trailer.[1] A gasoline motor for switching-service

[1] Weight on driving-wheels, 33,800 pounds; tractive power, 8200 pounds. Average monthly mileage of 6000 miles, making round trip of 206 miles daily.

was tried on the Pennsylvania Railroad in 1909. It weighed 42,000 pounds, with speeds of eight and of twenty-two miles an hour, and hauled twenty loaded cars on a level track. Some further data have been published as to the use of such cars on the Ann Arbor Railroad, upon a line of 300 miles. In June, 1911, the three cars there in use were operated at a cost of 13.73 cents per car-mile against a train-mile cost of 60 cents. Under the two-cent-a-mile rate of fare, the revenue was 43 cents per train-mile. The cars, all-steel, cost $22,500 each, and the interest-charge was estimated at 13 cents per car-mile.

Standard of Motive-power Efficiency

A discussion of motive-power efficiency should include a reference to some standard of such efficiency for purposes of comparison. A distinction is to be observed between data as to economic efficiency and as to cost; for the efficiency of a steam-generator is measured by its absorption of heat in thermal units, while the cost of combustion varies with the calorific value of the coal consumed and also with its price per ton. There have been instances in railway operation in which a very considerable decrease in the annual fuel-consumption has been neutralized by an advance in the price of coal.

On the New York Central Railroad, in 1913, coal-consumption constituted 58 per cent. of the total locomotive-cost per mile. Though the average performance in that year increased 896 miles per locomotive, with decrease in total consumption of 60,194 tons, the average price of coal increased six cents per ton. As a consequence, the total expenditure for coal increased by $278,814; an increase tantamount to a dividend of five per cent. on a capital investment of $5,576,280. If there were included in this statement the average caloric value of the coal consumed, the importance of ascertaining the relation of cost to efficiency would be made more apparent.

The comparative efficiency of locomotives as mechanisms is largely a matter of design which, as to steam distribution, is measured by the inclosed area on the indicator-card. As the drawbar-pull exerted is proportionate to this area, it is therefore a measure of comparative efficiency. In other respects, a comparison of annual tonnage-miles may furnish a more adequate standard as to the merits of different designs for the same freight-service than an average of the annual cost of repairs. The cost-data as to repairs are not in fact efficiency-data, even as to mechanical excellence of construction. The character of workmanship would be more definitely established by the ratio of hours of labor on repairs to the annual mileage. The main element of efficiency in a locomotive is its tractive power and, for purposes of comparison in this respect, a third group of physical data is required. Such data are obtained from the measurement, by a dynamometer, of the power developed at the locomotive-drawbar, or the drawbar-pull.

In this whole estimate of comparative efficiency there is an interrelation of data as to design, construction, cost and operation, which it is impracticable to coördinate in a single group, for purposes of comparison, or to measure by a single unit. But it may be considered that, as fuel-consumption is at the beginning of such a series of data and drawbar-pull at the end, a standard of motive-power efficiency for most practical purposes, from a technical point of view, may be found in a comparison of the amount of drawbar-pull that is made available by the consumption of a definite weight of coal. Where locomotives are operated in the same service on the same runs and with the same quality of coal, this standard should be sufficient. If a comparison is to be made between locomotives using different qualities of coal, the ratio may be determined by the relative calorific value, which may vary from 8000 British thermal units for slack to 14,000 units for anthracite or for semi-bituminous coal.[1]

Tests of this character develop the theoretical efficiency of locomotives. To compare their value for continual service, another factor must be included in the comparison, in addition to fuel-consumption and tractive power; that is, the factor of time. How many hours per day has the locomotive been in profitable service? In that period, how many pounds of tractive power have been developed as drawbar-pull, and with what fuel-consumption? Any useful standard of efficiency must take into account whatever information is of practical value, as to the relative merits of locomotives as tractors, for this, at the last, is the true measure of motive-power efficiency. It would not be necessary to obtain such data continuously as to all of the equipment, but only for each locomotive at such intervals as would give confidence in the reliability of the resulting averages as a just basis for comparison.

The results which would follow the application of statistics of this character to railway operation may be briefly stated. From an annual comparison of all the locomotives on any road on the basis as above indicated, a conception might be formed of the varying potential efficiency of that road as a measure of transportation, that could not have been afforded by any other statistical data. The advantages that would result from the general application of the pound of tractive power developed per hour of service as a basic unit in railway operation would be made apparent by such comparisons as are here suggested. The total theoretical tractive power of

[1] Tests of coal in use on the Atchison, Topeka & Santa Fé Railway, in 1907, from thirty different sources, gave a range of from 10,261 units for slack to 13,847 units for the best quality; so that the best coal was more efficient as a heat-producer by 31 per cent. over the poorest. Of the different qualities tested, three ranged between 10,000 and 11,000 units, eleven between 11,000 and 12,000, ten between 12,000 and 13,000, and six were over 13,000.

William Garstang, International Railway Congress, 1910.

the entire locomotive-equipment of the railway system of this country at a given date having been ascertained, the potency of that system as an instrumentality of transportation might be definitely established; as also the ratio of the service which it actually performed at that date to that of which it was theoretically capable.

If the valuation of our railway system, which is now in progress, were to include statistics, not only as to the number and commercial value of the tractor-units belonging to that system, but also as to their theoretical and actual tractive power in pounds, such statistics would have great practical importance in a discussion of the relative efficiency of the railways of which that system is composed. The efficiency of the locomotive as a tractor is the real basis of efficiency in railway operation.[1]

[1] Much of the technical information in this chapter has been obtained from the "Report of sub-committee on Railroads, and Locomotives of To-day," and the contributed discussion on "Steam-Locomotives of To-day," published in the Journal of the American Society of Mechanical Engineers, January, 1915; also from the publications of the International Railway Congress; from "Economics of Railway Operation," M. L. Byers, 1908; "The Utilization of Fuel in Locomotive Practice," W. F. M. Goss, in Bulletin 402, U. S. Geological Survey, 1909; and personally from E. P. Ripley, President, Atchison, Topeka & Santa Fé Railway System; from E. M. Coapman, Vice President, Southern Railway Company, and from C. A. Goodnow, Assistant to President, Chicago, Milwaukee & St. Paul Railway Company.

CHAPTER IV

ROLLING-STOCK

Early Forms of Railway Cars. English and American Types

The rolling-stock on the British railways was developed from the colliery-wagon and the stage-coach. As the colliery-railways became utilized for general traffic, the wagons were used for carrying goods, protected from the weather by tarpaulin-coverings. Live stock was transported in wagons provided with railings, and fourth-class passengers as well, without seating them. Afterward, these wagons were roofed over and closed in for general goods-traffic.

The passenger-carriages were similarly developed from the stage-coach by placing three coach-bodies back to back as compartments. The gentry preferred to remain in their own carriages, loaded on an open car, rather than to be associated with the commonalty, until a compromise was effected by assigning them, as first-class passengers, to special compartments more luxuriously upholstered. This class-distinction was further extended by separating the working people, as third-class, in plainly furnished compartments. Luggage was placed on the roofs, railed in, or in the spaces between the curved bodies, as in the boot of a stage-coach. As the early railways on the Continent were, for the most part, planned by British engineers, the wagons and carriages introduced by them have persisted as types to the present time. In fact, it was not until 1892 that passage from one car to another, otherwise than along the running-boards, was made practicable by the introduction of "corridor-trains."

In the United States, different physical and social conditions have controlled the character of the rolling-stock, as of other factors in railway operation. The incentive to railway construction was not to secure cheaper and more expeditious means of carrying coal to market. The governing condition was the want of highways for commercial and social intercourse. It was not a question of putting flanged wheels under existing coal-wagons and stage-coaches, but of providing vehicles for goods and travelers in the cheapest way. There were a few early imitations of the English railway-carriage, and the name of "coach" for a passenger-car still lingers in the railroad man's vocabulary, though the name of "wagon" for a freight car has not gained recognition. The freight-car for goods was from the beginning closed in and roofed over, and, as a safety measure, sliding doors instead of hinged doors were used on all cars with side-openings. The flat car, or platform car, was more common than the open coal-car, sometimes known as the "gondola," as lumber was a more general article of railway traffic, and for this reason the flat car was longer than the English coal-wagon.

But the one feature which profoundly differentiated American rolling-stock from the English types was the center-bearing four-wheel truck. Its superiority to the rigid wheel-base is obvious in its facility for continuous adjustment to the alignment of the track, whether that be due to curvature or to defective maintenance. Though this is a matter of greater moment upon hastily and cheaply constructed roads than upon those which are really "permanent ways," it has also the merit of neutralizing the horizontal and vertical oscillations of a vehicle in motion. For these reasons, the center-bearing truck was in general use in the United States long before it had gained recognition elsewhere, and with far-reaching consequences in other respects.

Rolling-stock design may be separated into three elements: the body, the underframe, and the running-gear. The body of the car, being merely a receptacle or a shelter, has been variously modified to meet the differing requirements of commerce, of travelers and of railroad operation. The underframe receives directly the shocks and strains from starting and stopping a train and from variations in speed while in motion. These strains are transmitted to the car-body by the bracing in the side and end frames, and to the center-bearing truck through the main cross-sills or bolsters.

The general structure of rolling-stock is designed to resist the strains occurring in train-service. The lighter the rolling-stock, the less is the shock upon its structure in starting and braking a train. The greater the speed, the more important it becomes to reduce the weight of the car relatively to the acquired momentum of the train. The relation of empty weight to tonnage-capacity is also of prime importance in connection with the profitable application of tractive power in train-service. This matter is kept carefully in view in designing freight-equipment, though but little attention is given to the seating-capacity of passenger-cars in proportion to their weight. Here, the comfort and convenience of travelers has been foremost, and considerations of social efficiency have overborne regard for economic efficiency.

Social efficiency has also been influential in the numerous designs of rolling-stock for special classes of traffic. Hence the varieties of freight-cars, as coal-cars, lumber-cars, live-stock cars, furniture-cars, etc.; and in passenger-service of mail-cars, express-cars, baggage-cars, smoking-cars, parlor-cars, sleeping-cars, dining-cars and observation-cars; and in railroad working equipment, snow-plows and wrecking-cars.

Many of these various designs originated in the United States and were influenced by peculiar traffic-conditions, as the grain-car, the tank-car, and the refrigerator-car. The ordinary box car was built of enlarged dimensions for carriage of light and bulky commodities until the size of the "furniture" car reached the roadway clearance-limits. The open live-stock car was closed in and furnished with facilities for feeding and watering in transit. For the transportation of valuable animals, padded stalls were provided, heated and ventilated, with accommodations for attendants, and such cars were well characterized as "palace stock-cars."

One of the most valuable of the special types of freight-cars that have originated in this country was due to the physical and social environment in which it was developed. The extensive mileage of our railway system, with a uniform gauge of track, covering half a continent from ocean to ocean and from the Great Lakes to the Gulf of Mexico, has invited an interchange of commodities produced under different conditions of soil and climate that was facilitated by the intense competition for such long-haul traffic between rival transportation-lines by land and by sea. The radius of profitable distribution of perishable commodities was limited by vicissitudes of weather and by their tendency to decay. These conditions acted adversely to each other. The inherent heat of vegetable products was hastened if the car containing them were tightly closed; if the car were ventilated, they were liable to damage by dust or by a sudden change of temperature. These difficulties were overcome by the adaptation of the common household-refrigerator, first to the fresh-meat traffic. The car-body was lined with material that is a poor conductor of heat, and its contents were thus protected from external variations of temperature. The inherent vegetable or animal heat was absorbed by ice, introduced through the roof into boxes at the end of the car, and the temperature within was accordingly controlled by the indications of a thermometer exposed to view from the outside.[1]

The framework of the English passenger-carriage was so strengthened by the compartment bulkheads that no reliance was placed upon the side-frames to stiffen the underframe, and side-doors were therefore not objectionable as a structural feature. The American car was not only longer, but, as it was not divided into compartments, dependence was placed upon the side-frames to give rigidity to the underframe, and side-doors were only provided for in baggage-cars. Entrance was therefore made over platforms at the ends; a construction that admitted of communication throughout the train. This feature, which was a matter of course in a democratic country, was an objection where class-distinctions were observed. The advantage of such intercommunication in railway operation has, however, forced its adoption abroad, though with reluctance. The seclusion so highly prized was made less desirable by occasional acts of

[1] See Chapter VI, pp. 344–348.

robbery, and even of murder, in isolated compartments. A compromise was accepted in the introduction of a passage-way or corridor along one side of the compartments. In Germany and in Switzerland, and to some extent in Italy, the open car is coming into use because of its greater seating capacity; so great has been the effect of the substitution of a center-bearing-truck for a rigid wheel-base! From a social as well as from an economic standpoint it has dominated the whole passenger-train service.

For many years, the underframe was not sheathed underneath. The occupants were subjected to noise from the running-gear, to dust and draft through the cracks of the loosely jointed and uncarpeted floors and to possible injury from the floor-joists being torn out in case of derailment. Further protection against this contingency was even sought in constructing the whole body of the car with staves, hooped like a barrel, with peep-holes in the sides and entrances in the heads; the idea being that, in the event of a derailment, the car-body would leave the trucks and roll over instead of being smashed to pieces. A car of this construction was long preserved as a curiosity on the South Carolina Railroad. In the days of the strap-rail, a broad and stout plank was suspended between the trucks, and just above each rail, by braces from the underframe, as a protection against "snake-heads" penetrating the floor.

Though the interior fittings of the early American equipment were less luxurious than in the European compartment-carriages of the same period, necessary provision was made for the comfort of their occupants which was painfully lacking in the same class of equipment abroad until a much later date. The arrangement of the seats in parallel rows was due to the end entrances, and the turn-over seat-backs obviated the necessity for turning the cars to avoid riding backward, as well as the propinquity of strangers facing each other.

By degrees, the car-bodies were lengthened from forty to fifty and sixty feet, to seat a larger number of passengers, with relatively less dead weight. The increase in length was accompanied by improvement in trussing the side-frames, by a greater use of iron rods as tension-members and of iron plating to strengthen the joints. The space in the underframe between the flooring and the sheathing was filled with sawdust or other material to deaden the noise from beneath. The deck-roof with upper light and ventilation was substituted for the low continuous roof. While no class-distinction was observed, smoking was only allowed in specially designated cars. These cars often included a "conductor's office," which served as a private lounging-room for favored friends and, in the Southern States, one end of such cars was usually reserved for negro passengers.

There was a gradual improvement in the treatment of the exterior of the car-bodies with respect to paint and varnish, approaching more nearly to the superior finish of English railway-carriages which had been inherited from coach-builders. The interior finish depended upon the price of the car and the taste of the purchaser. Hardwood veneer was generally used, varying in material and design with changing fashion in furniture. The upholstery varied, under similar conditions, from enameled cloth to carpet-stuffs and furniture-plush.

Sleeping Cars

A substantial improvement in passenger-equipment followed upon the introduction of the sleeping-car, which was developed in the characteristic American environment, beginning with an experimental car on the Cumberland Valley Railroad in 1836.[1] By 1859, sleeping-cars were in use between Albany and Buffalo. The ordinary passenger-car was fitted up with three tiers of berths, as in the open steamboat-saloons. No bedding was provided other than mattresses and pillows, until the service was undertaken by companies organized for the especial purpose.

One of these sleeping-car companies came under the control of George M. Pullman in 1864, and to him the traveling public owes the specially designed and luxuriously fitted cars with which his name will always be associated. To his mechanical judgment and power of organization have also been due many of the improvements in design and construction of passenger-equipment and in provision for the comfort of travelers, now in general use in other countries as well as in the United States. Mr. Pullman introduced the six-wheel truck to sustain the heavy weight of his cars, also steel-tired wheels. But his most valuable improvement was the vestibuled platform, patented in 1887, which provides a protected passage-way from car to car, ingeniously contrived to utilize the entire end-surfaces of adjacent cars as buffers. The adaptation of cars to night-service in this country was followed by the construction of cars specially designed for long-distance journeys, as parlor-cars, dining-cars and observation-cars. In the provision of such facilities for comfort and convenience of travelers, the railroad managements of the United States have been pioneers.[2] For the comparatively short railway trips in Great Britain, sufficient rest at night could be obtained in the ordinary compartment-carriages, with the aid of traveling-rugs. For the longer continuous journeys between London and Scotland, sleeping-carriages were placed on the West Coast Route in 1873, and Pullman cars on the Midland Railway in 1875. "Corridor sleeping-carriages," with eight wheels and forty-two feet in length, were introduced on the London & Northwestern Railway in 1883. Before that time, no vehicle over thirty-three feet in length had been in use, because of the diameter of the turntables. Upon the Continent, no other provision was made for comfort in night-travel than a hired pillow, until long after luxurious nocturnal accommodations had become general in the United States.

[1] "When Railroads were New," p. 171.
[2] See Chapter VI, p. 316.

Development of the Running Gear. The Bogie Truck

The running-gear of English rolling-stock was developed from that of the four-wheel colliery-wagon, with inside journals and without springs. Subsequently, pedestals were attached to the side-sills of the underframe and the axles rotated in boxes fitted for vertical motion in the jaws of the pedestals. Bearings of brass or other anti-friction metal were interposed between the journals and the top of the boxes, which also served as receptacles for lubricating material. Before the introduction of springs, the shocks from inequalities in the track-surface were transmitted directly to the underframe. The length of the original English car-bodies was limited by the load which could be carried upon an underframe supported by a pair of axles, and by the length of rigid wheel-base that could safely traverse the maximum curvature in the track. Provision was afterward made for longer car-bodies by introducing an intermediate axle, but the rigid wheel-base was still restricted by the track-curvature.

While different traffic-requirements induced differences of design in car-bodies, the design of the underframes in American rolling-stock has varied from English prototypes in the manner in which resistance is offered to the stresses of tension and compression in train-service. It was from the long-coupled wagon swiveling on a king-bolt, that the American center-bearing truck was developed. The underframe of the rigid wheel-base was separated, by this device, from the underframe of the car-body and became an independent unit in rolling-stock design. The rigid wheel-base could be shortened nearly to the diameter of a car-wheel, and the underframe became a truck-frame. One of these truck-frames was connected with the underframe of the car-body, near each end, by a center-bearing, pivoting freely upon a center-pin or king-bolt through the cross-sill or body-bolster. The rigid wheel-base, so shortened, traversed curves which were unsafe for the older type of running-gear. The shocks from the track, that were before transmitted directly to the car-body at four points, were now divided at eight points, and the resulting angular motion was further lessened by its reception at two points in the median line of the car-body.

The center-bearing truck was a decided advance in efficiency, since it permitted the construction of rolling-stock of greater length and loading-capacity than was before admissible. It is attributed to the inventive genius of Mr. Jervis, the engineer who built the Mohawk Valley Railroad, between Albany and Schenectady, about 1831, and was introduced under the eight-wheel passenger-car built by Ross Winans, in 1833, for the Baltimore & Ohio Railroad, together with his invention of outside journal-bearings. Steel springs are said to have been first used under the locomotive "York," on the same road, in September of that year. Prior to that time, in England, as in this country, passenger-car bodies were carried on four wheels, slung in leather braces like the body of the stage-coach from which they had been developed. The first steel springs were probably of the semi-elliptic type. As late as 1870, there were ten-ton freight-cars in use on Southern roads which were carried on trucks without side-sills or cross-sills. A long and heavy semi-elliptic spring resting in seats on the journal-boxes served as the side-sill, and the ends of the truck-bolster were attached to the middle of these springs.

The center-bearing truck was subsequently modified in important details. Among these was the floating bolster, resting upon steel springs, either coiled, elliptic or semi-elliptic; and equalizing-springs that received the shock from the journal-boxes through a bent bar upon which the springs rested, that in turn supported the side-sills of the truck-frame. The purpose of this complex spring-system is to divide and minimize the shocks transmitted through it from the track to the car-body. The efficiency of the center-bearing truck for this purpose, and also in shortening the rigid wheel-base, has led to its general use throughout the world. Its efficiency has been further increased by the introduction of the six-wheel truck, which not only conduces to easier riding qualities but also permits the construction of rolling-stock of increased capacity and weight.[1]

The use of steel as a construction-material has, however, brought about a return to the use of the four-wheel truck under heavy passenger-equipment. On the Pennsylvania Railroad, the four-wheel truck is used under cars 70 feet in length, seating 88 passengers, weighing (light) from 118,000 to 120,000 pounds and 140,000 pounds maximum loaded weight; the bodies weighing from 93,000 to 96,000 pounds. The load-limit is preserved of the standard 5½ by 11-inch journal. With coil-springs over the journals, elliptical bolster-springs and space for lateral play of the bolsters, the equalizing-springs were discarded without affecting the easy riding of the cars; though perhaps this might not be the case on a poorer track. Investigation proved that much of the jolting was due to the action of the unbalanced forces in the truck-frame when brakes are applied, and this was remedied by anchoring the dead-lever to the body-underframe.

A pair of four-wheel trucks weighs from 10,000 to 15,000 pounds less than a pair of six-wheel trucks of the same carrying capacity, which is a saving of eight to eleven per cent. in a car weighing 120,000 pounds. The saving in cost of maintenance has been found to be approximately in proportion to the reduction in the number of wheels and axles. In an experimental test on the Pennsylvania Railroad, thirteen cars with six-wheel trucks offered as much resistance as fourteen with four-wheel trucks.[2]

[1] Mention should also be made of the Lightner journal-box, an American invention, in which the interposition of a plate under the top of the journal box and over the bearing, made it much easier to remove a worn-out bearing by slightly relieving the weight upon it.

[2] "Four-wheel Trucks for Passenger Cars," Roy V. Wright, Journal Am. Soc. Mechanical Engineers, March, 1916. Cast-steel truck-frames are also used to some extent under freight-cars exceeding 60,000 pounds in capacity.

The introduction of the center-bearing truck in the construction of rolling-stock in the United States brought about a transfer of the axle-bearings from the underframe of the car-body to the truck-frame. In this change of structure, the stresses from the superincumbent weight were transmitted through the side-sills to the center-bearing by the interposition of the body-bolster, which therefore became an important member of the underframe. The body-bolster should be sufficiently rigid to transmit these stresses without sharing any part of the superincumbent weight with the side-bearings. The side-bearings are intended simply to diminish the lateral swaying of the car-body in rounding a curve, or in passing over low joints, frogs or crossings. There is no tendency in the truck itself to resume its normal position after leaving a curve, except from the reaction of the flanges against the rail. If this reaction be neutralized by friction of the side-bearings, the flanges may grind against the rail long after the curve has been passed. Reduction in flange-wear reduces rail-wear, as well as train-resistance. It is therefore important that, when a car is at rest, the body-bolster should sustain the entire superincumbent weight, without assistance from the side-bearings.

Drawgear and Couplers

A description of the characteristics of American rolling-stock would be incomplete without some notice of two important accessories — the drawgear and the brakes. The drawgear has been developed from the links and hooks by which the tramway coal-wagons were connected in trains. Injury from shocks in train-service was obviated by the intervention of a pair of spring-buffers in compression at each end of the wagon. This simple arrangement has continued in British and Continental equipment to the present time. Neither the spring-buffers nor the coupling hooks were ever in use in the United States. A more complex drawgear was devised that replaced them both. The buffer-shocks were taken by a central cast-iron drawhead connected by stout rods with an interior casting, containing a set of steel springs through which the strains of train-movement were transmitted to the underframe of the car. The cars were connected in trains by links held by pins through the drawheads.

This loose coupling connection became increasingly objectionable as cars were built of greater capacity and weight. The free play of three or four inches in the links, rendered necessary for facility in coupling, produced successive shocks to each car in a train, as it was started, or else its motion was checked. As locomotives increased in tractive power, the trains were of greater length. In a train of twenty cars, the locomotive would move some six or seven feet before the last car would be in motion, and the momentum thus suddenly imparted to it resulted in severe shocks to the drawgear and the underframe. When the train was in motion and its speed was slackened, the forward car in the train received the full shock as the slack was taken up. These alternating effects took place at each change of grade and were so severe on the couplings, pins and drawgear as well as on the car bodies, that twenty freight-cars made about the practicable limit of safety with a fully loaded train.

The link-and-pin drawgear was even more objectionable from the hazard in coupling cars so equipped. As early as 1869, railway managements in this country were seeking some device for diminishing this hazard. Difference in the height of drawgear was so common a cause of injury in coupling, that a uniform height of drawheads was a condition necessarily precedent to the adoption of any coupling appliance operated by impact, and the yardmen did not care so much for self-couplers as for deadwoods over drawheads. By 1875, the managements had determined to experiment with couplers without links and pins, though no such appliance had as yet been devised that was applicable to freight-cars. Two devices had appeared for coupling passenger-cars which involved a novel principle, that of coupling by impact with hooks in a vertical plane; the Miller coupler and the Janney coupler.[1]

In 1885, the Master Car Builders Association tested forty-two self-couplers. Twelve of these were further tested in the next two years and, in these tests, the fact became established that link-and-pin couplers could not be efficiently used on freight-trains with power-brakes. In 1888, it was determined to experiment only with devices that coupled automatically in a vertical plane, and to establish a uniform contour-line for the coupling surfaces of all such devices. This conclusion was made of practical effect by the patentees of the Janney coupler, who generously waived their exclusive right to the use of such contour-lines; and all couplers of this character were thereafter designated as the "Master Car Builders' type." This appliance was further improved by an attachment that enabled the coupler to be operated by hand from the side of the car and which could be so set as to prevent the hooks from catching each other when it was not intended that a car should be coupled by backing against it. In 1893, this type was made compulsory in the United States by the passage of the Railway Safety Appliance Act, to take effect January 1, 1898. The action of this coupler was rendered more efficient by the adoption of a standard height of drawbars for freight cars by the American Railway Association, fixed at 34½ inches with a maximum variation of three inches between empty and loaded cars.[2] In 1893, forty-four per cent. of the casualties to trainmen occurred in coupling cars; in 1909, they were reduced to seven per cent.

[1] Charles F. Hatch introduced Miller platforms and the air-brake on the Eastern Railroad of Massachusetts in 1872. "The Eastern Railroad," F. B. C. Bradlee, p. 78. The Miller platform and hook-coupling are still in use on the Boston, Revere Beach & Lynn Railroad (narrow gauge).

[2] For further information on this subject, see "American Railway Management," p. 38, and "Problems in Railway Regulation," p. 318.

Further Improvements in Automatic Couplers, End-Platforms and Vestibules

The increased length and tonnage of freight-trains has correspondingly increased the severity of the shocks and strains to which drawgear is exposed. Its component parts have been gradually improved in design and strength to meet these conditions, until it has become an expensive and complicated accessory to freight-equipment. With closely coupled cars, it is necessary that the resilience of the buffer-springs shall allow sufficient compression to enable the locomotive to make at least one revolution of its driving-wheels before it has to overcome the inertia of the entire train. Yet if these springs are too weak, the resulting impetus causes destructive shocks to the drawgear and unexpected train-partings that add considerably to the repair-account. The manner in which this troublesome problem was solved in this country and the general adoption of the solution throughout our railway system, are in striking contrast to the course pursued on European railways with reference to the same subject. It is an example of the value of government authorities' coöperating with railway managements in furthering railway efficiency.

From 1871, the same matter had been under consideration by British railway managements, in connection with the Board of Trade. By 1886, they had decided to use a "coupling-pole" with a hook at its end, to render it unnecessary to go between the wagons to hook up the couplings. Even after American managements had generally adopted couplers of the Master Car Builders type, their use was deemed impracticable on European railways because of the universal use of separate spring-buffers. In 1899, a British Royal Commission reported that an automatic coupling-system was desirable and recommended experimental research. In 1908, at a competitive test conducted by the Italian Society of Railway Engineers, the American type was found to be too heavy and costly, and too difficult to adapt to European rolling-stock, and the first prize was awarded to a coupler of Italian origin. In a competition under the auspices of the French government, the first prize was awarded to a device of French origin. Up to June, 1914, the subject of an automatic coupler adaptable to European rolling-stock was still in an experimental stage.

In couplers of the Janney type, the vertical hook opens and closes by rotation around a pivot within the drawhead; a feature that distinguished it from the previous Miller type, in which the horizontal movement of the coupling-hooks was controlled by springs. The Janney type was also unique in that the slack between the opposing hooks was taken up by springs in compression. These couplers were first applied to passenger-cars, and their additional weight caused the end-platforms to sag until by improved construction they were more firmly attached to the underframe.

A further improvement was effected in the vestibuled platform, first introduced on Pullman cars. The deck-roof was extended over the platforms, which were also inclosed, including the steps. By this means, persons passing from car to car were protected from exposure to the weather and from falling from the platform while the train was in motion. The interior of the cars was also protected from drafts and from dust through the opened doors. The open end of the vestibule was faced with broad steel plates that surrounded the passage-way and were connected with the end-frame by stout half-elliptic springs with a flexible covering, by which the faces of opposing vestibules were firmly compressed together. This device in itself constitutes a powerful buffer that distributes a colliding shock over a large surface, and the shock is thereby transmitted to the body-frame. In case of collision or derailment, it is now no longer possible for the end-platforms to override and for the ends of the cars to telescope. The whole train reacts as an unit to such shocks, and the injurious effect of such accidents is accordingly lessened. This feature has been imitated on European carriages so far as to provide a covered way through the train, but, unassociated with couplers of the American type, it has not the same potential value in case of accident.

Hand-brakes and Power-brakes

The improvement of drawgear, as accessory to the speedier and safer connection or disconnection of cars, as well as in securing them more firmly while in train-service, has been accompanied by an even more remarkable development in brake-gear, for arresting the motion of the cars, either singly or in trains.[1] The brake to the horse-drawn vehicle was adapted to the four-wheeled coal-wagon by a lever at the side of the frame, acting on wooden brake-blocks applied to a single pair of wheels. Increased power was obtained by a wheel, mounted on a staff at the end of the wagon, which operated the brake-lever by winding a chain on the staff; the pressure thus obtained being held by a ratchet. The application of this form of brake to the four-wheel truck required a double leverage in the intermediate rigging. Then this double leverage was duplicated to operate the brakes on both trucks from either end of the car and, at this stage, the development of the hand-brake virtually ceased; except that the wooden

[1] It is difficult for railroad men of the present generation to believe that train-service could be safely conducted without any braking apparatus; trains being checked or stopped solely by reversing the action of steam in the cylinders. Yet it is stated that, on the Newcastle & Frenchtown Railroad, in Delaware, "when the signal of an approaching train was heard, the slaves around the station would rush up to it and seizing hold of the cars, drag back on them with might and main, while the ticket agent stuck a stout stick through a wheel, and the whole train was thus gracefully brought to a standstill." M. R. Pugh, Trans. Am. Society of Civil Engineers, December, 1911.

brake-blocks were first plated with wrought-iron for which cast-iron brake-shoes were afterward substituted.

The hand-brake was not a train-brake; it was a car-brake. The speed of the train was arrested by the application of the brake to each car separately; an operation that was repeated successively on the several cars by the brakemen. Its efficiency depended, therefore, upon the number of brakemen on a train, upon their promptness in responding to the whistle-call for brakes and upon their muscular strength; as well as upon the leverage power of the brake-rigging. When freight-trains got up to twenty cars, the drawgear then in use reached the limit of its inefficiency, and the same was true of the hand-brake. The greater momentum of the heavier trains could not be diminished with sufficient rapidity for efficient train-service. Economy in train-service was accordingly restricted by the normal efficiency of the hand-brake, and the necessity became apparent for the application of brakes by mechanical power.

Several means were devised for accomplishing this purpose. In one device, known as the Creamer brake, the motive force was derived from a spring coiled on the brake-staff, like a watch-spring, which being released by connection with a rope stretched through the train, set all the brakes at once. But, with this device, the brakes could only be released by winding up each spring separately; therefore, it was of use only in bringing the train to a stop, and not in modifying its speed.

Attention was meantime directed to the employment of atmospheric pressure in the vacuum-brake that originated in England. By a steam-jet on the locomotive, the air was exhausted from a line of piping through the train connected under each car with a bellows-like device, the diaphragm of which was attached to the brake-rigging. This apparatus was in quite general use in Europe before it was introduced in this country under the name of the Eames brake. It was adopted on the New York Elevated Railroad, where it was not altogether satisfactory, as sufficient vacuum-pressure could not be maintained with stops at short intervals, nor did it act efficiently on trains exceeding a limited number of cars.

A more efficient method of braking a train was devised by reversing this process and using compressed air. The power obtained from an air-pump, operated from the locomotive-boiler, was applied to the brake-rigging by the motion of a piston in a cylinder under each car. This plan of the direct or "straight" air-brake was patented by George Westinghouse April 13, 1869, and was tested on the Pennsylvania Railroad in November of that year. Its merits were so apparent that it soon supplanted the vacuum-brake in this country. It had the advantage of maintaining a higher initial pressure than that of the atmosphere and of retaining it during an application of the brakes, without a continuous draft upon the boiler for steam. It arrested the motion of the train more rapidly and was more efficient in gradually modifying its speed. But when the direct air-brake had been brought to this stage of efficiency, its usefulness was terminated by a further development of the same principle, again due to the inventive genius of Westinghouse and patented by him January 29, 1873.

Instead of operating the brakes directly by air-pressure, it was now used indirectly in the "indirect action" apparatus. The piston that actuated the brake-rigging was restrained by the constant presence of air in the reverse-end of the cylinder at a predetermined pressure. Whenever from any cause this pressure was slightly reduced, a connection was opened between the other end of the cylinder and an auxiliary storage reservoir under the car, which had been filled directly from the train-pipe with air at a higher normal pressure. The piston then acted on the brake-rigging; provision being made for the escape of the air from the reverse-end. By this device, the braking-power was constantly energized and acted independently on every brake in the train, whenever the pressure in the train-pipe was reduced, either by the release of air in the locomotive-apparatus, or by a valve connected with a cord in each car, or by the train breaking apart. In this latter event, the rear portion of the train will be stopped automatically before it can collide with the forward part. Subsequently, an attachment was added in each passenger-car and in the freight caboose-car, which, by a similar release of air-pressure, operated a whistle-signal in the locomotive-cab, in place of the signal by a bell-cord stretched through the train.

Air-brake Control of Long Trains

The improvement in drawgear and in brakes was contemporaneous. Without the principle of coupling in compression, the application of mechanical energy to braking was impracticable. Until both of these principles had been brought into general use, the length of a freight-train was necessarily limited by the strength of the weakest link or pin that connected its constituent units together. The conditions which limited the number of cars in a train, relatively restricted the tractive power of the locomotive by which it was drawn. Indeed, the economies effected by the introduction of locomotives of the articulated type would have been impracticable without the vertical-hook coupler and the quick-action air-brake. In providing for the greater strain brought upon the drawgear by power-brakes, the automatic coupler became more complicated in construction and much more costly than the link-and-pin drawgear.

By reason of the increased capital investment so required, the experimental stages of this experience were principally confined to passenger-trains, which had been brought into general conformity as to equipment of couplers and power-brakes, and largely through the use of Pullman cars, before the resulting advantages had been made sufficiently manifest to warrant their application to freight-trains. This next step was hastened by the pressure of diminishing freight-rates upon the cost of service. It was the narrowing margin between the ton-mile rate and the ton-mile cost that forced the construction of cars of greater capacity, their operation in longer trains and the introduction of locomotives of increased tractive power, which consequently placed the American managements in the van of railway progress. Yet neither of these elements of greater efficiency could have been so successfully utilized but for the contemporaneous introduction of the vertical-hook coupler and the air-brake, which have made it practicable to operate freight-trains of four times their former length, and indirectly have contributed to profitable increase in the tractive power of locomotives.

Beyond the limit of twenty-car trains, the necessary control of speed was not to be obtained by hand-brakes; but the application of power-brakes to freight-cars could only come into experimental use on refrigerator-cars and stock-cars which were already equipped with vertical-hook couplers, and which, therefore, could be kept together in the train. Then a few more cars were so equipped and placed at the head of fast freight-trains. But this was found impracticable while the other cars in the train were still equipped with link-and-pin couplers. For as the power-brakes were applied in the forward part of the train, and the slack between the following cars was taken up by the arrested motion, the resulting shock told too severely upon the structure of the rolling-stock. Though the number of cars equipped with power-brakes gradually increased in number, they were of no more use than hand-brakes when merely distributed discontinuously through a train. Only when it became compulsory to equip all freight-cars, could the number of cars in a train be increased to correspond with the maximum tractive power of the larger locomotives. The momentum acquired by a train of fifty cars, each loaded to fifty tons' capacity and headed by a heavy locomotive, is so much greater, proportionately, than that of a train of twenty cars moving at equal speed, that greatly increased efficiency was demanded of the air-brake apparatus in arresting its motion. The chief direction for improvement lay in securing quicker action through the train. Though it was a matter only of seconds, still, in reducing even that brief lapse of time, there was a field for obtaining better results.[1]

These facts were established in a series of tests between competing devices, including buffer-brakes as well as vacuum and compressed air-brakes, conducted, in 1886, at Burlington, Iowa, by a committee appointed

[1] The Department of Safety of the Interstate Commerce Commission recommended the installation of air-gauges and emergency-valves in the caboose cars of long freight-trains. By means of the gauge, variations in the pipe-line pressure might be observed and measures taken to insure the safety of the train, if the pressure should fall too low, or if the train had been uncoupled for any purpose and then re-coupled; or to indicate the effect of leaks in the pipe-line, or of inefficient inspection at the terminals. The valve would also give control of the braking power of the train in an emergency.

by the Master Car Builders Association. In these trials, made with trains of twenty-five and of fifty empty freight-cars, it was found that the shocks caused by the application of the brakes to the forward car in a fifty-car train, some ten or twelve seconds before the brake-pressure was effective on the rear car, were too severe upon the drawgear and underframes. In 1887, a similar committee conducted another series of tests at the same place on fifty-car trains with an improved Westinghouse apparatus, electrically controlled. In these trials, the lapse of time between the effective application of brakes on the first car and on the last car in the train was reduced from twelve to five seconds, and stops were made in two-thirds of the distance, as compared with the trials in the previous year.[1] Notwithstanding these results, the committee still doubted the practicability of applying electrically-controlled brakes in general freight-service. Mr. Westinghouse then quickened the action of the mechanism without an electrical attachment and, by the end of the same year, fifty-car freight-trains were being satisfactorily operated with his improved apparatus.

The efficiency of the "quick-acting" brakes on passenger-trains was being gradually affected adversely by the increase in weight and number of cars in a train and by the higher rate of speed. In 1894, the Westinghouse Company introduced a "high-speed" attachment, by which the degree of pressure in the train-pipe, and in the auxiliary reservoirs under the cars, could be varied above the normal pressure at the discretion of the engineman. By this means, the effective pressure on the brake-shoes could be increased or diminished with the varying speed of the train and the condition of the rail-surface. The importance of this improvement had been made apparent in experiments conducted by Mr. Westinghouse and Sir Douglas Galton in England in 1878. The purpose of these experiments was to determine coefficients of friction between the brake-shoe, the wheel and the rail at different speeds. From these tests, a definite ratio was established for the application of varying degrees of brake-pressure under different conditions and without skidding.

It has taken many years of experience to establish a satisfactory relation in braking-operation between the locomotive, the individual cars and the assembled train. Brakes are now applied to every wheel in the train, except the locomotive truck-wheels.[2] There is a more accurate adjustment of brake-leverage and greater thoroughness in design and construction of the brake-rigging. Increased efficiency has been attained by making the apparatus more positive and responsive in application and release by electric control, by maintaining the brake-rigging in uniform condition,

[1] In 1886, a fifty-car train, at a speed of 20.3 miles an hour, was stopped in a distance of 354 feet in 16 seconds; and at 40 miles an hour, in 922 feet in 22½ seconds. In 1887, similar trains at 21½ miles an hour were stopped in 160 feet in 7 seconds, and at 36 miles an hour, in 460 feet in 14 seconds.

[2] On French trains, the brakes on the driving-wheels are applied independently by steam-pressure.

by a better method of applying a heavier brake-shoe, and by the use of the clasp-brake with two flanged shoes to each wheel.[1] The grip of the brake-shoe has been improved by bits of cast-iron inserted in soft steel, and by layers of steel in diamond-formed meshes placed in the molds in which the cast-iron is poured.

The ordinary style of electro-pneumatic brake has been in use on electric lines for over eight years under several thousand cars, and, on the New York Subway, has given good results under the most severe service in the world. Its efficiency was exhibited in tests made on the Pennsylvania Railroad in 1913. The experiments were made with a train of twelve steel passenger-cars with four-wheel trucks, weighing nearly 1000 tons. At a speed of sixty miles an hour, its kinetic energy was estimated at 224,000,000 foot-pounds, equivalent to 70,000 nominal horse-power. At this speed, with the ordinary "high-speed" brake and under usual working conditions, such a train could be stopped within 2000 to 2200 feet. On this trial, with the same apparatus and at the same speed, the train was stopped within 1600 to 1800 feet and, with improved appliances, in a distance of 1000 feet, or within its own length! It is of interest to note how this was brought about.

Rating the usual working pressure at 100 per cent., or the weight of the empty car, the emergency pressure is available to 125, 150 or 180 per cent., as may be desired. With 150 per cent. of working pressure, the stop from 60 miles an hour was shortened from 1600 to 1400 feet. With the electro-pneumatic brakes, the distance was reduced to less than 1200 feet and, in one trial with flanged brake-shoes, to 1049 feet. The use of flanged brake-shoes was estimated to shorten the stops approximately 12 per cent., and the relative proportion of area bearing upon the wheel to the total area of the face of the brake-shoe was found to exert an important influence upon brake-performance.

Maximum Brake Energy. Safety Appliances

The demand for increased efficiency in brake-apparatus was illustrated by Mr. W. B. Turner, Chief Engineer of the Westinghouse Brake Company, in the discussion upon the paper by Mr. Dudley.[2] In 1890, with a

[1] Clasp-brakes, Master Car Builders Association Rules, 1915.

All passenger cars with four-wheel trucks, weighing 96,000 lb., and all with six-wheel trucks, weighing 196,000 lb., should be equipped with clasp-brakes.

New York, Ontario & Western Railway Hot Box Delays. Comparison of clasp-brakes and single-brakes on four-wheel trucks.

In thirty months, cars with clasp-brakes made 1,873,500 miles with 10 hot boxes, an average of 187,350 miles per box-trouble. The remaining equipment, with single-brakes, made 11,407,200 miles with 88 hot boxes, an average of 130,760 miles.

[2] See "Brake Performance on Modern Steam Railroad Passenger Trains," S. W. Dudley, Journal Am. Soc. Mechanical Engineers, November, 1914, p. 373.

train-weight of 280 tons at 60 miles an hour, the energy to be dissipated amounted to about 33,000 foot-tons and the stoppage-distance was 1000 feet. In 1913, with a train-weight of 920 tons at the same speed, the energy was 111,000 foot-tons, or almost four times greater. With the old-style air-brakes, the collision energy of such a train, at the point where the first train would have been stopped, would still be 48,000 foot-tons, and there would yet be about 460 feet to run. But the modern train used in the Pennsylvania Railroad tests, equipped with the new apparatus, can be stopped in 860 feet, at which point with the old equipment it would still have a speed of 43 miles an hour and a collision energy of 57,000 foot-tons, or about twice the energy of the train of 1890 at the beginning of the stop.

The stoppage of a heavy train at high speed within a brief space of time has been successfully accomplished by combining its component vehicles into a consolidated mass, thus eliminating their relative motions. The problem now to be reckoned with is the continuous adjustment of brake-pressure to varying conditions of car-weights, train-speed and rail-surface. As the matter was put by Mr. N. A. Campbell, of the New York Air Brake Company, in the discussion on Mr. Dudley's paper, it is the adjustment of resistance to rotation and rail-adhesion. Further improvement in brake-apparatus is being directed to this problem, but when comparative tests are reduced to distances of less than a hundred feet and to periods of less than a second, theoretical efficiency would seem to have been approached within 90 per cent. The energy dissipated in the conversion of motion into heat, in the action of the air-brake, has been illustrated by the statement that, while the acceleration of a heavy train from a state of rest to a speed of 60 miles an hour cannot be accomplished in less than six minutes, the same train at that speed can be brought back to a state of rest by the improved brake-system in one-eighteenth of that time, or in twenty seconds!

The air-brake, in connection with the automatic coupler, has greatly facilitated train-service; yet the importance of these inventions in this respect, however highly estimated, is not to be compared with their value as an element of social efficiency. As applied to cars of steel construction, they have minimized to a great extent the effect of collisions or derailments upon the occupants of trains so equipped. They have also contributed largely to the welfare of trainmen by relieving them from liability to injury occurring in the use of handbrakes and link-and-pin couplers, especially in handling freight-cars.

Protection from such injuries has been further secured by attention to minor details in car-construction, such as the rigging for manipulating couplers without going between the cars, and also running-boards, ladders and grab-irons (or handholds) for access to car-roofs. The character and position of these appliances has been made the subject of regulation in the Safety Appliances Act of 1893, as amended April 1, 1896, and March

2, 1903.[1] Improvement in other details might tend still further to mitigate the consequences of railroad accidents as, for instance, by more thoroughly interlocking the couplers, to prevent the separation of cars in a train, and by firmly keying the center-pin to the body-bolster instead of relying solely upon safety-chains, to prevent the dragging of a car-body off the trucks.

Car Wheels. Chilled Iron; Steel, Forged and Cast

The mechanical and economic advantages derived from the introduction of converted steel into the useful arts, affected roadway and locomotive construction and design before its influence was apparent in car-construction. The front pair of wheels on the colliery tram-wagons was of cast-iron as early as 1750, though the back pair was still of wood to give a better grip to the wooden pole or "convoy" that was used as a brake until the wooden rails were plated with iron.[2] The type of wrought-iron wheels that subsequently prevailed was derived from the ordinary spoke-wheel with iron tire, and it long continued in general use on European railways until replaced by steel-tired wheels.

The independent character of the evolution of a railroad system in the United States is seen in this as well as in other details of rolling-stock construction. The production of a fine quality of soft gray iron in the Eastern States and the lack of mechanics skilled in making wrought-iron wheels, resulted in the use of cast-iron wheels with chilled treads, as a cheaper substitute. These wheels were at first of single plate but were afterward cast in double plate, with brackets to support the flanged rim. Such skill was attained in the manufacture of these wheels, in the mixture of iron of different qualities, in the heat treatment, in chilling and in the molding and casting, that no serious attempt was made to use wrought-iron for this purpose except for driving-wheel tires.[3] Whether for lack of the proper grade of iron or of workmen skilled in their manufacture, cast-iron wheels have not been favorably considered by European railway managers. Yet in this country, they are in successful use under heavier loads and at speeds equally as high as are customary elsewhere.

In 1886, cars of 50,000 pounds' capacity, weighing 31,000 pounds, were replacing cars of 20,000 pounds' weight and capacity, and the weight of the 33-inch wheel was gradually increased from 450 to 500, 600, 700 and 750 pounds, but without any theoretical basis for calculating the stress in

[1] By order of the Interstate Commerce Commission, March 13, 1917, these requirements were made effective July 1, 1917. Up to May 16, 1916, out of a total freight-equipment of 2,510,214 cars, 1,821,086 or 73 per cent. had been so equipped.

[2] "Internal Transport and Communication in England," Edwin A. Pratt, 1912.

[3] The depth of the chilled or white metal should not exceed one inch or be less than a half-inch at the middle of the tread.

cooling or the shocks from use. About 1909, the Master Car Builders standard for the 33-inch wheel was modified to conform to changing conditions, but the introduction of cars of 60,000, 80,000 and 100,000 pounds' capacity was putting them to a still severer test. To meet these requirements, the wheel-weight was increased to 840 pounds under freight-cars and to 950 pounds under tenders.

Long-continued brake-application occasions abnormal strains in the wheels from heating. On a car weighing 40,000 pounds and loaded to 100,000 pounds, a brake-pressure of 3500 pounds per wheel, at ten miles an hour on a long grade, generates heat that must be dissipated through the brake-shoe and the wheel-rim. There is also a lateral thrust that may reach 40,000 pounds to which the wheel-flange may offer a shearing resistance ranging from 40,000 to 125,000 pounds. Such a lateral thrust when the wheel-rim is heated by long-continued brake-action, may result in a broken flange. The effect of a heavily loaded car upon track out of order, or when striking guard-rails and crossings at high speed, likewise causes shocks that defy calculation. Taking all these conditions into consideration, it is surprising that a brittle metal like cast-iron can be adapted, by skill in metallurgical treatment and in mechanical design, to offer successful resistance to the strains and shocks to which a wheel is now submitted in railroad operation. Yet chilled wheels are made that are capable of satisfactory service under heavy freight-equipment; they are still liable to broken flanges, although the flanges have been thickened as much as the frog and switch clearances will permit. Sharp flanges cannot be remedied, although flat spots may be ground out of the tread, as may be done with steel wheels by turning. Cracked plates are principally due to the heating action of brake-shoes, which also causes broken flanges from circumferential cracks in the tread.[1]

The first use of steel in wheel-making was in the substitution of crucible steel for Lowmoor iron in driving-wheel tires. The purpose was to obtain greater resistance to wear and to tensile strains, but it was too expensive a material for car-wheels. Converted steel, being a cheaper material, replaced crucible steel for driving-wheel tires, and steel tires on cast-iron centers were used in locomotive-trucks and tender-trucks. They were gradually introduced under Pullman cars and other high-class passenger-equipment. The solid pressed-steel wheel then followed, doing away with

[1] Derailments from wheel failures in eleven years, from 1902 to 1913. Interstate Commerce Commission Reports.

Broken or burst wheels	2,871
Broken flanges	6,625
Loose wheels	1,121
Miscellaneous defects	1,136
Total	11,753

Out of 33,270 derailments in this period, the ratio caused from defective wheels was 3.85 to 1, as compared with broken rails, and 2.39 from broken flanges alone.

retaining-rings and bolts, and the operations for removing and applying the tires, by which the first cost and upkeep were so much reduced that for many years solid steel wheels have been used in place of steel-tired wheels; though their cost in proportion to their wearing qualities prevented their general use under freight-equipment.

In 1903, Mr. C. T. Schoen established the manufacture of solid forged and rolled steel wheels on a commercial basis. Up to 1908, this wheel was in use on 9000 locomotive-trucks, on 32,000 passenger-cars and on 165,000 freight-cars and tenders; a total of 206,000. In 1907, Mr. J. M. Hansen developed a process for forging steel wheels by hydraulic pressure alone and, in April, 1908, the United States Steel Corporation began the manufacture of wheels of this character.

The steel wheel is a safeguard against broken flanges. The flange of a chilled wheel can be broken with a pressure of 60,000 to 100,000 pounds, while a pressure of 526,000 pounds was required to break off the flange of a steel wheel. The Master Car Builders' standard axle has an ample factor of safety with four axles loaded to 150,000 pounds, which is the limit for chilled wheels. With 10 per cent. excess loading, which is permitted, the hopper-car weighing 39,000 pounds with steel wheels, can be loaded to 121,000 pounds and still be within the permissible load on the standard axle. The 33-inch wheel of rolled steel weighs about 800 pounds and may make 240,000 miles with three turnings against a life of about 80,000 miles for chilled wheels.

The American Steel Foundries corporation has undertaken to meet the requirements of heavy freight-service at a reasonable cost with the "one-wear" cast-steel wheel. This wheel is cast in a mold on a rapidly revolving table. With the first flow of metal, an alloy of manganese is introduced and thrown into the surface of the tread to harden it. The wheel is next submitted to an annealing process to relieve internal stresses from cooling, and is then ground to the standard contour of tread and flange and made perfectly round. The finished wheels are each submitted to a drop-test of 500 pounds from a height of 6½ feet to detect imperfections, and are then paired, as to circumference, by tape measurement, in order to diminish the tendency to sharp flanges and "slid-spots," caused from pairing wheels of unequal sizes upon the same axle.[1]

[1] Weight of wheels and length of guarantee against defects.

	Weight, Pounds	Guaranteed
Chilled wheels 30-ton car	625–690	6 years
Chilled wheels 40-ton car	675–700	5 years
Chilled wheels 50-ton car	725–800	4 years
Rolled or forged steel	750–800	
"One-wear" cast-steel	600	

Guarantee for steel wheels same as for chilled wheels.

Wheels are removed when slid-spots exceed 2½ inches. These flat spots in rolled or forged steel wheels are removed by turning; those in wheels with chilled or hardened tread, by grinding. A process has been devised for filling these spots in cast-steel wheels by electric welding and restoring the contour of the tread by a portable grinding wheel. Another defect exhibited in chilled wheels is known as "shell-outs," also caused by the heating action of the brakes, by which the surface of the tread crumbles in spots. The hammering effect at high speed of such defects in the tread has been experimentally determined at from twenty to sixty per cent. of the static load.[1]

When a steel wheel is removed on a foreign road and replaced by a chilled wheel, the Master Car Builders' Rules require that the owner of the car shall be paid the difference in value, if the responsibility for the removal rests with the foreign road. The charge for removing, turning and replacing steel wheels is $3.25 per pair, and, on an average, every wheel is turned twice. Consideration should be given to the saving effected by doing away with the turning; for the investment in shop-room and machine-tools for this purpose and the accompanying labor-charge and cost of maintenance, is evidently very large.

The use of steel wheels under freight-equipment is confined principally to steel hopper-cars of heavy capacity. It was vaguely estimated that in 1914 about 3,000,000 steel wheels were in use out of about 20,000,000 wheels under all classes of train-equipment. On the Louisville & Nashville Railroad there are 83,000 "one-wear" steel wheels in use. Steel-tired wheels are still used under passenger-equipment and heavy tenders. On the Delaware, Lackawanna & Western Railroad, 15,000 solid steel wheels, 33 inches in diameter and weighing 815 pounds, had been used under steel hopper-cars up to September, 1915. A 36-inch solid steel wheel, weighing from 875 to 900 pounds, is used under new passenger-equipment and under all tenders. In a comparative test of rolled-steel wheels and steel-tired wheels, 36 of each kind, made on the Atchison, Topeka & Santa Fé Railroad System in passenger-train service, there was an average mileage between turnings of 105,000 miles for the rolled wheels, and of 111,000 miles for the steel-tired wheels. The rolled wheels add about 4000 pounds more weight to a seventy-foot passenger-car as compared with steel-tired wheels.[2] The cost per mile run of the solid steel wheel and of the chilled wheel is

[1] A flat wheel with a spot three inches long, under a car weighing, loaded, 50,000 pounds, strikes a hammer-blow of 104,000 pounds at a speed of sixteen miles an hour. Railway Mechanical Engineer, February 16, 1916, p. 60.

[2] Much of this information has been obtained from the managements of the railroads mentioned; also from an article on "Car Wheels" by George L. Fowler, in Cassier's Magazine for March, 1910; from a report on the "Use of Steel in the Construction of Locomotives and Rolling-stock" by D. F. Crawford, General Superintendent of Motive Power, Pennsylvania Lines West of Pittsburgh; from Proceedings of International Railway Congress, Berne, 1910; and from American Steel Foundries, April, 1916.

about equal, allowance being made for interest on the increased investment in the steel wheel; but the general use of the latter would add about $315,000,000 to the investment in car-wheels on our entire system.

Steel Construction for Car Trucks and Frames

The substitution of iron for wood in truck-construction was first applied to the diamond-truss truck-sides for freight-service; but under cars of very large capacity, that design is now being superseded by the solid steel truck-side, in which the side-rail and pedestals are cast in a single solid piece. Wooden side-rails are still continued in service under passenger-cars, being strengthened for the six-wheel trucks by iron plates. From 1895, when converted steel came into general use, it replaced iron for all car-construction, including axles, excepting journal-boxes and other details, for which cast-iron is equally serviceable and cheaper.[1]

Much ingenuity has been displayed in the construction of car-springs. Beside the varieties of elliptic and semi-elliptic and coil springs made of steel, rubber has also been largely used to diminish the shock between the journal-boxes and the side-rail of the truck. Attempts have also been made to utilize the elasticity of air in compression, but steel still predominates as the most suitable material.

The use of steel in freight-car construction has greatly contributed to economic efficiency in railroad operation by increasing the possible proportion of tonnage to empty weight. This matter was made a subject of general interest by promoters of narrow-gauge projects. They emphasized the fact that the standard-gauge freight-cars weighed twice as much empty as their possible tonnage-capacity, while, in the narrow-gauge equipment, the two were equalized. As a consequence, advocates of the standard-gauge strove to neutralize this argument by improving their equipment in this respect.

The ordinary freight-car, at first, like other features of railroad construction, was a development of the colliery-tramway. The underframe was similar to that of the old coal-wagon; a rectangular framework, with some perfunctory bracing, that carried the pedestals in which the axle journal-boxes had a little vertical play. In the United States, this underframe was adapted to the center-bearing truck by the intervention of a cross-timber or body-bolster, to which the truck was pivoted by a center-pin or king-bolt. The strains from traction were transmitted from the drawgear to the trucks indirectly through this underframe, and in a manner that racked it at every joint in its structure. As the demand increased for heavier loads and longer trains, this tendency to distortion

[1] An important step toward simplicity in construction has been introduced by the Commonwealth Steel Company in making the whole freight-car truck-frame of a single casting, thereby eliminating bolts, nuts, etc.

of the underframe was resisted empirically by increasing the dimensions of its members and by strengthening its joints and bracing.

The first really efficient improvement in the underframe was the introduction of central longitudinal sills in pairs, reinforced against tensile strains by iron rods connecting the two drawgears at the ends of the car, by which the shocks and strains of train-service were transmitted directly through the train, without otherwise affecting the structure of the underframe. As automatic couplers came into general use, their increased weight was transferred from the end-sills to these center-sills. The body-bolsters were also framed into these sills, which thus became the backbone of the car and the spinal column of the train. To this foundation, strengthened by the floor-joists and the intermediate braces, the car-body was framed and, though many differences in detail were developed, the underframe remained unchanged in general design until the substitution of steel for timber in car-construction.

This change was initiated when the loading-weight had reached 60,000 pounds. This load, concentrated at the center-bearings of the trucks, caused the body-bolsters to droop, and they were accordingly stiffened by flitch-plates between layers of plank in the composite bolster. The substitution of an all-steel bolster permitted an increase of loading to 80,000 pounds. Even in cars 36 feet in length, the side-sills were not sufficiently rigid to sustain this weight without undue strains upon the underframe, which was strengthened by six truss-rods extending from bolster to bolster.

As it was not practicable to further increase the load, which was desirable in mineral traffic, attention was then directed to the design of an all-steel underframe, which was introduced in 1897 on the Bessemer & Lake Erie Railroad for cars of 100,000 pounds' capacity and 46 feet in length; though it did not come into general use until 1901. This radical change in construction was not important in cars for general traffic, which could not be uniformly loaded to such a capacity as to warrant the additional weight. Still, by degrees, steel was used for underframes, upper-frames and for roofing; and an all-steel hopper-car of 80,000 pounds' capacity, weighing about 42,000 pounds, was introduced on the Pittsburgh & Lake Erie Railroad in June, 1897. The tendency at present is for all freight-cars to have steel underframes; hopper-cars and hopper-bottom gondolas of 110,000 pounds' capacity all-steel, and lighter gondolas with steel hoppers.

It has also been found necessary to build caboose-cars with steel underframes, to prevent them from being crushed where heavy "pushers" are used. Similar damage to the ends of wooden box cars from the severe strains to which they are subjected has induced the introduction of ends of corrugated steel for cars of large capacity.

The use in Europe of goods-wagons, built wholly of iron, dates back to 1866, but, to any noticeable extent, only to 1880. Even in 1910, they were only in experimental use in France, Great Britain and Russia. These open goods-wagons are usually mounted on four wheels for a load of six tons, with six wheels for twenty tons and with eight wheels for greater loads. The coal-wagons have eight wheels and carry from 27 to 40 tons. In fact, only a small percentage of freight-equipment in Europe is either entirely of iron or of iron with wooden floors. Cars of this construction are objected to because the repairs are more difficult, take more time, and are more costly. They have to be frequently coated with red-lead and tar as protection against rust, and, as covered wagons, they do not sufficiently protect the contents from temperature variations. On account of the scarcity of timber, the climatic conditions and other features of a tropical environment, freight-equipment of steel construction is more generally in use in India, South Africa and Australia. At the end of 1908, out of 94,850 goods-wagons reported as of "iron or with iron underframes," 29,505 were in use in Europe, principally in the German and Austrian empires; and 65,345 in India, South Africa and Australia. Up to 1910, no passenger-cars, except for underground-railways, had been constructed wholly of steel, except in America.

Freight-car Capacity in the United States. All-steel Freight Cars

Increase in capacity of freight-cars in the United States dates from 1855 to 1860, when eight-wheel cars of 10,000 pounds' capacity were substituted for four-wheel cars of 7000 pounds. By 1865, there were box cars of 15,000 pounds and coal-cars of 20,000 pounds. In 1873 the standard capacity of the several classes of freight-cars was as follows:

	Light	Capacity	Capacity to Total Weight
	Pounds	Pounds	Per Cent.
Box	18,700	28,000	59.94
Stock	20,295	20,000	49.62
Gondola	17,280	28,000	61.81
Coal	17,350	30,000	63.36
Coal (4-wheel)	7,635	10,000	56.82
Coal (4-wheel)	7,635	12,000	61.22
Coal Hopper	18,750	37,000	66.37

The notoriety given by promoters to the relative advantage of narrow-gauge equipment as to the ratio of paying load to lighter weight, gave an impetus to the further development of this subject on standard-gauge roads, so that, by 1876, 40,000 pounds was the capacity-standard, 50,000 pounds in 1883, and 60,000 pounds in 1885, for all classes. In 1895, the Pennsylvania Lines West of Pittsburgh built 70,000-pound cars for coal and ore traffic.[1] From 1890 to 1908 the average increase in weight and capacity of the entire freight-equipment of Pennsylvania Lines West, increased as follows:

Average weight	45 per cent.
Average loading, loaded cars	70 per cent.
Average loading, all cars	50 per cent.

At present the wooden box car of 40,000 pounds' capacity weighs about 22,000 pounds; that of 60,000 pounds weighs 30,000 pounds; that of 80,000 pounds, 34,000 pounds; and that of 100,000 pounds, 38,000 pounds. The proportion of empty weight to loading capacity is, therefore, respectively 55, 50, 42.5, and 38 per cent.[2]

Cars have also been introduced of 110,000 pounds' capacity, and, experimentally, of 120,000, 130,000, 140,000 and 150,000 pounds. In 1911, the Pennsylvania Railroad Company built hoppers and gondolas 52 feet in length to carry 160,000 pounds; and, in 1913, a gondola car was built for the Norfolk & Western Railway Company to carry 200,000 pounds on six-wheel trucks, with length over all of 46 feet, 10 inches, outside width of 10 feet, 4 inches, and total weight of 65,200 pounds, or 32 per cent. of its capacity.[3]

[1] INCREASE IN CAR AND LOAD WEIGHTS, 1876–1898

	Light Weight	Paying Load	Total	Percentage of Total Weight	
				Car	Load
1876	20,500	20,000	40,500	53.62	42.38
1882	24,000	40,000	64,000	37.50	62.50
1889	27,700	60,000	87,700	31.59	68.41
1895	36,000	80,000	116,000	31.04	68.96
1898	38,500	100,000	138,500	27.80	72.20
10 per cent. excess	38,500	110,000	148,500	25.93	74.07

"Economical Size and Capacity of Freight Cars." L. F. Loree. International Railway Congress. Paris Meeting, 1900, XVIII, p. 63.

[2] ESTIMATED COST AND WEIGHT OF STEEL-UNDERFRAME BOX CAR. AMERICAN RAILWAY ASSOCIATION STANDARD

Capacity	Weight	Cost	Ratio of Allowable Loading to Weight
Pounds	Pounds		
60,000	38,200	$1,025	1.7
80,000	41,400	1,100	2.1
100,000	43,000	1,145	2.6

Ten per cent. overloading allowed. Byers, "Economics of Railway Operation," 1907, p. 647.

[3] In 1915, the Norfolk & Western Railway Company placed in service 750 steel gondolas of 90 tons' capacity and has ordered 1000 more. With permissible excess-loading of 10 per cent., the paying load is 75 per cent. of total weight. Railway Age Gazette, March 31, 1916.

In 1910, out of 243,809 freight-cars, the Pennsylvania Railroad Company had 74,466 all-steel, 53,662 with steel underframes, and 115,681 of all-wood construction. The all-steel cars were gondola, hopper, coke and flat cars. The steel underframes were box cars. In twelve years, with an average of 11,000 of such cars in service, 18 all-steel and 126 steel underframes had been destroyed, against about 20,000 of wooden construction. During this period, the larger car-building companies had built about 311,000 all-steel cars, of which 300,000 were gondolas, hopper and dump cars for coal, coke and ore; and 241,000 with steel underframes, of which 75,000 were also gondolas and hopper cars, and 125,000 box cars. Out of 280,000 freight-cars built in the United States and Canada in 1907, 72 per cent. were of some form of steel construction. Out of 133,117 freight-cars ordered in 1911, 28,418 were all-wood, 54,605 had steel underframes and 50,094 were all-steel. In 1914, one-half of the total freight-equipment was either all-steel or with steel underframes. Eighty per cent. of the all-steel cars were open coal and ore cars.[1]

Comparative Efficiency of Wooden and Steel Frame Box Cars

A comparison of the economic efficiency of standard wooden box cars of 60,000 pounds' capacity with steel-underframe cars of 100,000 pounds' capacity appeared in the Railroad Gazette in November, 1897. A train of thirty steel-underframe cars with empty weight of 510 tons would carry a paying load of 1500 tons. A train of wooden cars of equal gross weight

[1] At the end of 1915, the Pennsylvania Railroad Company had 6500 steel box cars, representing an investment of $9,000,000. These cars are of 100,000 pounds' capacity and weigh 50,000 pounds with complete equipment.

All-steel Cars Ordered up to January 1, 1916

Description	Number	Per Cent. of Total
Hopper and gondolas	431,132	81.4
Box and house	30,562	5.7
Tank	26,306	5.0
Flat	24,047	4.5
Miscellaneous	17,953	3.4
Total	530,000	
Also 672,171 with steel underframes.		

Addition to Steel Freight Equipment, N. Y. C. & H. R. R.R. Co.

	1911	1912	1913	Total
All-steel	4,600	7,329	8,445	20,374
Steel underframes	11,836	18,754	29,627	60,217
Total	16,436	26,083	38,072	80,591

(2010 tons) would weigh, empty, 703 tons with paying load of 1307 tons, or 193 tons less of paying load. The saving in length of train would be more than 500 feet, with proportionately less resistance in rolling-friction and journal-friction, and a saving in repairs on account of fewer wearing surfaces and breakable parts. The proportion of paying load to empty weight could be much increased in cars with steel underframes, were it practicable to increase their length; but that cannot be done without a correlative change of spacing in the arrangement of doors in freight warehouses, coal-pockets, grain-elevators and other terminal facilities, which could only be made at an enormous cost.

In another comparison of cars of similar capacity and construction, the life of a wooden car costing $525 was estimated at fifteen years and that of a steel car costing $810 at thirty years; the cost of repairs to a wooden car at $40 per annum and of a steel car at $20. With interest at five per cent. the saving in the steel car, per ton-capacity per annum, was stated at 42 per cent., or $1.04 per ton. On a fifty-ton car, this amounts to $82 per annum, and on 500 cars in thirty years to $1,230,000. This estimate does not include the saving in cost of train-service due to difference in empty weight and carrying-capacity.[1] From more recent experience, it appears that acids in coal and coke corrode the floor-sheets and sides of steel cars quite rapidly so that, during sixteen years, the repairs on the bodies practically amount to rebuilding them; and that it would perhaps be more economical to scrap the body after twelve years' service. The total cost of freight-car repairs increased from $61 in 1908 to $80 in 1914.[2]

Statistics of Freight Cars in the United States

In 1905, the total number of freight-cars on our railway system was 1,727,620. In 1910, there were 2,133,531. Increase, 405,911. In 1914, there were 2,325,647. Increase from 1910, 192,116.[3] The increase from 1905 to 1910 was at the annual rate of 81,182 cars. From 1910 to 1914, the annual rate was 48,029 cars.

In 1905, the total tonnage-capacity of our freight-equipment was 53,036,495 tons; and in 1910, 76,450,660 tons. Increase, 23,414,165

[1] American Engineer, Car Builder and Railroad Journal, March, 1898.

[2] On the Bessemer & Lake Erie Railroad, where steel cars had been in use since 1897, the average cost of maintenance as compared with wooden cars was as follows:

Year	Wooden Cars	All-steel Cars
1905	$71.14	$27.83
1906	94.11	30.74
1907	118.50	39.21
1908	53.06	32.11

[3] See Appendix III, Table II.

tons. In 1914, the tonnage-capacity was 90,848,630 tons. Increase from 1910, 14,397,970 tons. The annual rate of increase from 1905 to 1910 was 4,682,833 tons, and from 1910 to 1914, 3,599,492 tons.

From the diminution in the annual rate of increase in both the number of cars and in the tonnage-capacity, it would seem that the freight-equipment of our railway system was gaining upon traffic-requirements.[1]

In 1905, box cars constituted 47 per cent. of the freight equipment, and coal-cars, 37 per cent. In 1914, about 44 per cent. was in box cars and 39 per cent. in coal-cars, which is an indication of the growing importance of the mineral traffic. The number of flat cars remained unchanged in nine years; the number of stock-cars increased one-half, and the number of tank and refrigerator cars has about doubled, as has also the number of cars classed as "other cars." In 1905, 54 per cent. of the total equipment was in cars of 25 to 30 tons' capacity and 26 per cent. of greater capacity. In 1914, 60 per cent. was above 30 tons and 27 per cent. was of 50 tons. In that year, 59 per cent. of the coal-cars and 8 per cent. of the box cars were of 50-ton capacity and over. The stock and refrigerator cars were principally of 30 tons' capacity and the tank-cars of 40 to 50 tons. Thirty-six per cent. of the flat cars were of 30 tons, 39 per cent. of 40 tons and 16 per cent. of 50 tons. This statement excludes cars in railroad use only (124,719 in 1914), and cars belonging to private concerns.

By far the largest proportion of the rolling-stock of our entire system is owned by comparatively few companies. In 1914, the proportion as to freight-equipment was as follows:

Districts	Corporations	No. of Cars	Capacity
Eastern	16	33.9 per cent.	35.5 per cent.
Southern	7	12.6 per cent.	13.2 per cent.
Western	15	25.6 per cent.	24.2 per cent.
Total	38	72.1 per cent.	72.9 per cent.[2]

The relative ownership of passenger-equipment of the same companies was as follows:

Districts	Corporations	No. of Cars
Eastern	16	37.7 per cent.
Southern	7	9.0 per cent.
Western	15	27.6 per cent.
Total	38	74.3 per cent.[3]

[1] The progressive increase in tonnage-capacity from 1905 to 1914 of the several classes of freight-equipment is given in detail in Appendix III, Tables III and IV.

[2] Appendix III, Table V.

[3] Appendix III, Table VII.

Steel Passenger-cars

Steel was not introduced into passenger-car construction to provide for greater capacity in proportion to empty weight, as in freight-car construction; but as a protection against fire, collisions and derailments. It was not so much a measure of economic, as of social, efficiency. It is true that iron was being gradually employed as tension-rods, in reinforcing wooden underframes and, in the form of plates, for sheathing the side-frames; but steel, as an important element in construction, was first brought into use for underframes in 1903, on the Chicago suburban lines of the Illinois Central Railroad Company, and at the suggestion of George Westinghouse. In 1904, twenty all-steel cars, designed by George Gibbs, were put in service on the New York Subway lines. In 1905, the Long Island Railroad Company equipped its electric lines with 134 all-steel passenger-cars, and all-steel motor-cars in considerable numbers were in service on the electrically operated lines in New York, Boston and Philadelphia. These cars were intended only for urban and suburban traffic, though occasionally a baggage-car or a postal car of all-steel had been experimentally placed in ordinary railway service.

The first substantial adaptation of all-steel construction for regular passenger-train equipment, was in connection with the operation of the Hudson River terminals of the Pennsylvania Railroad Company. Up to February, 1908, that company had built 686 all-steel cars, of which 392 were day-cars and 75 combination passenger-and-baggage cars. By 1910, there were 3117 all-steel cars in regular railway service.[1] In 1911, of 4075 cars ordered, 62 per cent. were all-steel and 14 per cent. were built with steel underframes. Of cars in use in December, 1910 and 1911, respectively, all-wood cars were 98.2 per cent. and 87.2 per cent.; steel-underframe cars, 1.0 per cent. and 3.5 per cent.; and all-steel cars, 0.8 per cent. and 9.3 per cent. There was an increase of 6642 all-steel cars from January, 1909, to January, 1913. Between January 1 and July 1, 1913, orders were placed for 1140 passenger-train cars, of which 1064 were to be all-steel and the remaining 76 were to have steel underframes. The construction of all-wood passenger-cars has now practically ceased.[2]

[1] See Appendix III, Table VIII.

[2] Additions to Steel Passenger Equipment, N. Y. C. & H. R. R.R.

	1911	1912	1913	Total
All steel	297	288	521	1106
Steel underframes . .	135	173	300	608
Total	432	461	821	1714

The transition from wooden to all-steel construction of passenger-train equipment was too great an undertaking to be generally attempted. The first experimental all-steel cars were so heavy and costly that efforts were made to combine the respective strength and lightness of steel and wood in a composite car, in which the frames and the side-sheathing below the window-sills were of steel; wood being still used for the upper siding, flooring, roofing, inside-lining, doors and window-frames. In some of these composite designs, the two materials were so judiciously combined that the resulting weight was only 2.5 per cent. greater than in the standard car of wooden construction of equal seating-capacity. Nevertheless, the growing opposition of the Public Railway Commissions, encouraged by popular dread of wooden cars of any kind, became a serious obstacle to the use of composite cars. As experience was gained in all-steel construction, it was found practicable to build an all-steel car of equal weight per car-seat by increasing the seating-capacity.[1]

The usual tendency to conform to tradition and to experience in any change of a typical character, was too strong to admit of any marked departure from the principles hitherto followed in wooden-car construction. The decrease in the proportion of weight to length and seating-capacity, was gained only as structural design conformed to engineering practice in the use of steel beams. The purposes to be kept in view were to concentrate the structural strains at the center-bearings and to resist the shocks in service that tended to distort the body-frame. In wooden construction, these ends were met by using the side-sills as foundation members, strengthened by tension-rods and by trusses in the side-frames; the end-sills being kept from sagging by truss-rods carried over king-posts placed where the side-sills were attached to the body-bolsters or transoms. This type of construction was analogous to that of a trussed bridge-span, but was limited, as to length between bolsters, by the available depth beneath the window-sills for suitably bracing the truss-panels. Such designs could be strengthened by the substitution of steel as a construction material, but with increase in weight.

Although steel cars built in the experimental period were much heavier

[1] PASSENGER TRAIN EQUIPMENT. JANUARY 1, 1916

	ADDITIONS IN 1915	UNDER CONSTRUCTION	IN SERVICE
All-steel	1250	1075	14,286
Steel underframes . . .	340	16	6,060
All-wood	906	3	41,382
Total	2496	1094	61,728

6744 wooden cars were retired in three years. Steel cars in service increased from 629, in 1909, to 14,286 on January 1, 1916. See Appendix III, Table XI.

than wooden cars, their weight with further experience was considerably reduced. Pullman sleepers built in 1907 weighed 72.5 tons; those built in 1910 weighed 63.6 tons. There has been likewise a reduction in the weight of day cars, in proportion to their length and seating-capacity. The first day cars built by the Pennsylvania Railroad Company were 58½ feet long, weighed 103,620 pounds and seated 72 passengers. Cars built at a later date, 70⅝ feet long and 78 feet between couplers, weighed 116,290 pounds and seated 88 passengers, with a reduction from 1433 to 1323 pounds per passenger, and from 1774 to 1646 pounds per linear foot. Wooden day cars built at the same time, 70 feet in length and seating 80 passengers, weighed 106,260 pounds, or 1327 pounds per passenger and 1519 pounds per linear foot. These weights may be compared with those of day cars having composite bodies and steel underframes, as follows:

Length, Feet	Weight, Pounds	Weight, per Linear Foot
66	110,230	1670 pounds
70	117,290	1675 pounds
72	118,170	1641 pounds
72½	119,050	1642 pounds

Variations in the weights here noted are to some extent due to the inclusion of accumulators and of axle-driven dynamos and appliances for lighting.

Steel Girder Frames and Other Improvements

Greater advantages from the change of material were to be gained by the use of steel in beams, either simple or compound. Here, there is an analogy to a vertebrate type of structure, instead of a trussed type; and it is on this principle that the general design of steel passenger-equipment is now being developed. It had its origin in the longitudinal central girders that were adopted in wooden freight-car construction, to transmit the shocks in service through the train, without affecting the body-structure of each car.[1] In steel construction, these girders are combined in a box girder, which takes the place of the side-sills as the foundation member of the whole car-body, as well as of the underframe. The evolution of this design may be likened to that of the structure of a ship's hull, in which the keel is the principal member and the kelsons are the subordinate members of the whole frame, into which are built the body-frames or ribs of the hull.

In the further development of this type on the Pennsylvania Railroad,

[1] Freight-cars should withstand shocks from compression of 300,000 pounds, whenever they are subjected to switching, and such shocks are often equivalent to 500,000 pounds. The center-sill construction is based on 400,000 pounds' compression. A dynamometer-car, weighing 51,000 pounds, ran down a grade at seven miles an hour and collided with a train of loaded cars with a shock of 607,000 pounds, the limit of the dynamometer record.

the central box girder, the side-sills, the floor-beams and the body-structure may be combined in panels of uniform dimensions, each panel including two window openings; so that the car-body may be of any practicable length between the center-bearings and be continued beyond those points in end-sections of different designs. As the rigidity of the structure does not depend upon trussing the side-frames, side-doors may be placed in any panel. Steel castings may be used in the underframes of the end-sections, with simplification of design as compared with underframes built of beams, with greater resistance to injury from collisions and without increase in weight. A provision, not required in wooden construction, has to be made for expansion and contraction in the longitudinal members.

The substitution of the central box girder for trussed side-sills as the foundation of the underframe, led to the elimination of the transom or body-bolster. The consequent lowering of the car-body brought about considerable changes in the construction of the trucks, which were also entirely of steel, and in the arrangement of the springs. These modifications are experimental, and have not yet fully met expectation as to easy-riding requirements. A considerable decrease has been effected in weight, however. The four-wheel truck under the standard wooden car on the Pennsylvania Railroad weighed 16,000 pounds and the six-wheel truck, 21,700 pounds. The trucks under the steel cars weigh, respectively, 12,500 and 19,500 pounds.

The method of panel-units has also been applied in side-truss construction in the motor-cars of the New York, Westchester & Boston Railroad. The panel-units are of pressed-steel sheets, one-quarter inch thick, connected by deep flanges. Each panel consists of the outside plate of a post, the letter-board and the diagonal bracing under the windows. These units are riveted to a plate at the top, to the side-sills at the bottom and, up the center, to pressed channel-shapes which complete the posts. The window-sills are formed by light, continuous double-channels (UU) with a light-channel intermediate post to the side-sill. The vertical load is carried mainly on the sides; the center-sills, transmitting only buffer-strains, are held in alignment by the panels formed by the cross- and side-sills. The roof of pressed-steel carlines is riveted to deck-sills which are carried on the bent-in ends of the side-posts; so that the car-body and frame practically form a structural cage. The sides are sheathed with one-sixteenth-inch steel sheets, carrying no load-stress but merely forming a curtain. The car has Pullman vestibules, and, without the motor-apparatus, weighs 85,000 pounds and seats 88 persons.

The American car-roof is characterized by the clerestory, which gives more height to the interior, and provides light and ventilation from above. This form of roof, however, adds nothing to the longitudinal rigidity of the car-body, nor transversely, except at the ends and by a few intermediate straight carlines. In fact, the clerestory is essentially an independent structure, superimposed upon the car-body itself. Its mechanical design is structurally weak, as each carline in it has six joints, and it is so low in proportion to its length that it is insufficiently braced lengthwise. Experimental efforts have been made, in all-steel construction, to substitute a roof of oval cross-section, with carlines in single pieces attached to the side-posts, or even made continuous with them. But this form of roof diminishes the height of the interior vaulting and excludes the features of upper lighting and ventilation; nor does it appear to be sufficiently stronger than the clerestory-design to offer much greater protection in case of collision or derailment.

Mention may here be made of an all-steel car of novel design, built for transferring baggage through the Hudson and Manhattan tunnels in connection with the through-train-service on the Pennsylvania Railroad. To avoid intermediate handling, the baggage is stowed in closed wagon-trucks at either terminal. These trucks are wheeled into side-openings in the car, over bridges formed by lowering the siding, and are held securely during transit by an interlocking arrangement controlled by air-pressure, which likewise controls the manipulation of the side-openings. This design deserves more particular attention, for it contains the germs of an innovation that might be of value in the handling of freight in less-than-car-load lots.

Advantages and Disadvantages of Steel-car Construction

The effect upon economic maintenance of the general use of steel in passenger-car construction is as yet uncertain. Ten years of experience has proved that, as with freight-equipment, rust is quite as serious a matter as is decay in wooden construction. Doors and window-frames of pressed steel soon rust out, and serious damage from this cause, especially behind the deck-screens, is only discovered when a car is shopped for general repairs. The steel siding is easily dented and can not be restored to its original surface. The roofing sheets become warped, even with vertical joints to provide for expansion. The joints themselves are rapidly abraded by the friction of flying cinders, and are corroded by the action of coal-gas.

These objections affecting the economic construction and maintenance of all-steel equipment, as well as others more directly affecting the comfort and convenience of passengers, are strengthening the tendency toward the adoption of standard passenger-equipment of a composite character, with the underframes of steel beams, the body-frames of structural shapes and the end-sections largely of cast-steel construction. Wooden flooring would then be laid on fireproof material, and the interior finish made of hard-wood veneering, with wooden doors and sash. The sheathing below the windows would also be of wood, and that between and above them of sheet steel, or perhaps of aluminum, or the newly discovered rustless metal, stellite, and the roof of wood, canvas-covered.

Steel-car construction is as yet in an experimental stage. The steel underframe of the box car, with wooden body and flooring, and of the platform car, also with wooden flooring, can readily be standardized and, in many details be brought into conformity with similar equipment of wooden construction. The same may be said of all-steel cars for coal and ore traffic. But many problems involved in the designs of steel passenger-equipment are still to be determined in the light of experience. These designs may be classified as the composite-type, substantially similar to the wooden car; the all-steel car, founded on transoms or body-bolsters and side-sills — the truss-type; and the car founded on a central longitudinal girder — the vertebrate type. The general adoption of this latter type would admit of the standardization in detail of passenger-equipment, of the manufacture of the several parts as stock, of ready repairs, and of a reduction in cost that should compare favorably in point of price with the wooden car, and with manifest superiority in economic and in social efficiency.

There are other difficulties to be overcome in all-steel passenger-car construction. The desire to banish fire-risk induces the disuse of wooden roofing, siding and flooring; still, consideration should be given to the discomfort thereby occasioned to travelers. For steel plating radiates heat rapidly and is sensitive to sound-vibrations. It is therefore more readily affected than wooden siding and flooring by change in external temperature and by noises. These objections are measurably removed by the use of a mixture of asbestos and magnesia with other non-inflammable materials, either in sheets or in plastic condition; though it is possible that the anti-inflammable property of some of these materials may diminish or disappear with chemical reactions induced by moisture. Wood must, however, still be used for sash-frames, for seat arm-rests and for blocking to which the sheet-metal can be attached by screws. This wooden material will weigh about 400 pounds. Other inflammable material may be required for seat-coverings and draperies. The style of decoration must conform to these changes in material, of which there is a premonition in the substitution of baked enamel for paint and varnish in the interior of the cars on the Hudson and Manhattan tunnel-lines.

Steel-car construction has necessitated novel mechanical processes. Experiments in connecting roofing plates by riveting and soldering proved unsatisfactory, and the plates are now welded by the oxy-acetylene process. Even such joints, being inelastic, in time become cracked and permit of leakage and rust. There are also evidences of electrolytic action where materials of different electrical affinities are brought in contact. These are but casual instances of the necessity for attention to details that will be required in anticipation of the complete substitution of steel in passenger-car construction. The change is so fundamental that it will be long before such details can be reduced to the uniformity which has been attained in many features of American rolling-stock, especially as to freight-equipment.[1]

Transition from Wood to Steel in Car Construction. Cost and Economy

The great changes in general design, and consequently in mechanical details, which follow upon the change in materials for construction, should be effected with careful attention to the preservation of existing uniformity in these respects. The economies to be expected from further standardization in rolling-stock design will, therefore, necessarily be deferred until experience has justified the opinion that the experimental stage has been passed in steel-car construction. During this transitional period, no important economies can reasonably be hoped for. New methods must be devised for meeting changed conditions, and "speeding-up" will be impracticable until these methods have been coördinated and applied to standard rolling-stock on an extensive scale. The shop-equipment required for working metal must be provided, while the appliances for wooden construction will be still in use. In addition to the enormous sums of money that will be needed to finance the general substitution of steel equipment, the shop-conditions connected with it will also call for a very considerable expenditure before economic efficiency can be restored. It is a much simpler and less expensive matter to provide the tools and to obtain the skilled labor for working in wood than in metal, and the reasons which apply to the restriction of locomotive-construction to establishments specially equipped for such work, apply with even greater force to the construction of steel rolling-stock. The opportunity for economic shop-efficiency is perhaps greater in car-construction shops than in locomotive-shops. The units to be built at one time are more numerous; and an absolute conformity in design may extend to minute details; the mechanical processes are fewer and simpler; American wood-working machinery has been so perfected that much of the work can be performed by unskilled labor. It is, however, more difficult to organize car-repair work efficiently, for

[1] It has taken many years for the Master Car Builders Association to establish standards for the multiplicity of parts involved in the construction of running gear, of brake- and coupler-rigging and of safety-appliances; matters of vital importance in the repairs of cars interchanged throughout our vast mileage. In this general interchange, certain dimensions should also be standardized, in order to comply with the minimum roadway clearance-restrictions existing on our railway system. After long consideration, the Master Car Builders Association has recommended standard dimensions for closed freight-cars to meet these requirements, as also to establish the relation between the length of such cars and the spacing of warehouse-doors.

As recommended, the inside dimensions of box cars are 36 feet in length, 8 feet 6 inches in width and 8 feet in height; special equipment not to exceed 40 feet 6 inches in length, 8 feet 6 inches in width and 9 feet in height. Maximum outside width, 9 feet 2 inches at 13 feet above top of rail.

much of it is of a minor character which is done by hand-work upon outdoor-tracks where it is likely to be isolated from supervision.[1]

The rapidly increasing substitution of steel rolling-stock indicates the necessity for corresponding increase in facilities for such construction in commercial establishments, so far as may be warranted by the financial condition of our railway system. In this connection, it may be of interest to arrive at an approximate estimate of the cost of this substitution. It may be assumed that all cars of 60,000 pounds' capacity, or less, are of wooden construction and should be replaced with steel underframes; say at a cost of $600 per car. In 1914, there were about 850,000 cars of this description.[2] The total cost of replacement would, therefore, be over $500,000,000. Add to these figures the cost of solid steel wheels at, say, $315,000,000,[3] and the increased investment in freight-equipment would total $815,000,000. On December 31, 1915, there were some 41,000 wooden cars in passenger-service and the cost of their replacement was estimated at $528,000,000. Therefore, the general substitution of steel for wood in the rolling-stock of our railway system would require a capital investment of not less than $1,343,000,000.

In the substitution of steel for wood in car-construction, consideration must be given to the extent and character of passenger-equipment, as well as of freight-equipment. The total passenger-equipment, in 1914, numbered 53,466 cars. Of this number, 23,490 were first-class passenger-cars and 13,607 were baggage, mail and express cars; or about 70 per cent. of the whole. Up to 1910, about 3100 cars were of all-steel construction and principally of these two classes, including 487 sleeping-cars. In 1914, the whole number of sleeping-cars owned by railway companies is given as only 636, and it is probable that these cars are now all-steel. There were 1282 dining-cars and 561 parlor-cars, which will ultimately be replaced by all-steel also. The remaining 13,890 cars are principally combination and second-class cars.[4]

It may be reasonably expected that, out of this total of 53,000 cars, not more than from 15 to 20 per cent. will be of all-steel construction. But steel underframes will ultimately prevail as with freight-equipment and, in addition, the end-frames and platforms will be of cast-steel, as a safety

[1] In May, 1914, the American Railway Association appointed a Committee on Standard Box-car Design. A sub-committee of officials of the mechanical departments and of representatives of prominent car-building companies recommended three types of box cars:

1. Double-sheathed wooden cars of 60,000 to 80,000 pounds' capacity.
2. Steel-frame, single-sheathed cars of 80,000 pounds' capacity.
3. All-steel cars of 80,000 to 100,000 pounds' capacity.

The reduction of the many different types to these standards would greatly diminish the number of repair-parts required to keep foreign cars in service. All the parts could be standardized and be held in stock by manufacturers.

[2] See Appendix III, Table III.

[3] See page 116. [4] See Appendix III, Tables VI and VIII.

device. The exterior of these cars with wooden side-frames will probably be partially sheathed with steel, but steel finish inside will not be favored because of corrosion from moisture. As already suggested, the body-frames may be of structural shapes instead of wood, and the flooring underlaid with fireproof material. The trucks, however, will be of steel. How long it may take to complete this replacement is mere conjecture. The average annual replacement may be estimated at 5000 cars of all descriptions. On this basis, it would require ten years to carry out such a substitution as is here contemplated. In the nine years, 1906 to 1914, inclusive, the annual increase in passenger-equipment has averaged about 1500 cars. There should be shop-facilities, therefore, for the construction of at least 6500 cars per annum. Some light on this subject may be obtained from a statement issued by the Census Bureau, June 15, 1916, as to the construction of steam and electric cars in 1909 and in 1914, which is summarized in Appendix III, Table IX. From this statement, it appears that in 1914 there were 131,799 freight-cars and 3558 passenger-cars built in the United States, exclusive of 2821 electric cars. It would seem, therefore, that the output should be virtually doubled to replace wooden passenger-cars by steel cars within ten years.[1]

Rolling-stock Defects

It is a difficult matter to establish any satisfactory standard of comparative efficiency in the Rolling-stock Department from statistical data. Something of this kind is, however, suggested by reference to the inspection reports of the Division of Safety of the Interstate Commerce Commission. A statement of the comparative percentage of defects in safety-appliances, compiled from these reports for 1910 to 1914, as to roads with equipment of 10,000 cars or more, is given in Appendix III, Table X. Where this statement shows a variation in five years of only between 1.5 and 2.0 per cent. of the total number of cars inspected belonging to a particular company, it may be inferred that the shop-efficiency there is of a higher character than where, in the same period, the variation was between 7.0 and 14.6 per cent. Other variations, as between 3.2 and 11.1 per cent. were probably due more to financial considerations than to shop-conditions. Taking the twenty-seven companies included in the table, the comparative result is as follows:

Defects	1910	1911	1912	1913	1914
Under 5 per cent.	14	17	9	11	11
Under 10 per cent.	12	10	16	10	15
Over 10 per cent.	1		2	6	1

[1] Information regarding steel-car construction not previously acknowledged, has been obtained from a valuable paper on "The Construction of Iron

From this comparison, it may be assumed that an average under 5 per cent. indicates a relatively high standard of shop-efficiency, and that such a standard has been attained in at least one-half of the railroad shops in this country.

An inference as to the weaker points in car-construction may be derived from a further report as to derailments caused by defective equipment. In ten years, from 1906 to 1915, the annual average has been as follows:

Broken wheels	275	Side-bearings	94
Broken flanges	575	Arch-bars	179
Loose wheels	109	Rigid trucks	124
Other wheel-defects	104	Power-brake hose	206
Broken axles	379	Couplers	181
Brake-rigging	421	Miscellaneous	375
Draft-gear	226	Total average	3,248

Under each of these heads, there has been a fluctuation from year to year with no apparent relation to the character of equipment or to car-mileage; and no marked decrease in any item during the period. The high average of derailments from broken wheels and flanges should be materially reduced with the increasing use of steel wheels. Derailments from defective draft-gear and brake-appliances are largely due to inefficient maintenance and inspection.

Comfort and Luxury in Car Design. Car-lighting

Economic efficiency is a paramount consideration in the design and construction of freight-equipment, but it yields to social efficiency where passenger-traffic is concerned; and in no other country as in the United States. In designing passenger-cars, the relation of weight to seating-capacity has hitherto been disregarded. Their interior fittings are the best of their kind, and decoration has been carried perhaps to excess, especially in Pullman cars. No crowned head of Europe enjoys more luxurious appliances for railway travel than are provided for the American citizen in his own land. This is conspicuously the case in appliances for lighting and heating passenger-trains.

The English stage-coach proprietor made no further provision for the comfort of his passengers than to seat them, more or less inconveniently, within or on his coaches; nor did the railway companies, in the transition period from horse power to steam. The railway carriage was the conventional stage-coach in all respects. The journeys were short and not usually prolonged into the night. The traveler who wished for light provided his own pocket-candle until the railway companies consented to light each compartment dimly by a candle placed in the roof; and this

Passenger Cars in the United States of America," by F. Gutbrod, Member of Board of Works, Berlin, published in the Bulletin of the International Railway Congress, November, 1912, *et seq.;* and from operating officials of some of our principal railway systems.

long remained the standard lighting-system on English railways, until it was replaced by oil-lamps in 1850.

As the four-wheel truck led to the long, open car on American railroads, so did the open car lead to a different system of train-lighting; first with a candle-lantern at each end of the car, for which an oil-lamp was afterward substituted. But neither of these illuminants gave more light than was sufficient for passengers to grope their way to or from their seats. An improvement in car-lighting followed upon the introduction in the early sixties of mineral-oil or kerosene, which gave a brighter light with less labor in cleaning and filling lamps, and less dirt and damage from grease-spots. After the clerestory or deck-roof became a common feature of construction, additional lamps were placed along the center line of the car; and this remained the standard lighting-system for many years.

The advent of the air-brake brought about a change in car-lighting, as in other features of train-service. About 1880 Mr. Westinghouse passed compressed air through a "carburetor," suspended under the car-roof, which contained absorbent material charged with a very volatile petroleum product, known as "88° gasoline." The resulting inflammable vapor was conducted through piping to suitable burners. It was found that changes in temperature greatly affected the carburetor, and the system remained in an experimental stage until about 1885, when it was much improved. As this "carburetor system" then equaled the kerosene lamp, as to brilliancy of illumination, and usually required attention no oftener than every ten days, it was gradually taking its place when rival methods of lighting with compressed gas supplanted it. The carburetor system is, however, still valuable where there are no facilities for storing either compressed gas or electric current.

The use of coal-gas for car-lighting originated in Europe, about 1870. Gas from city-mains was stored in a reservoir in the guards' van, being slightly compressed by water-displacement, and was thence conveyed through the train by pipes with hose-connections. This system may be considered as a normal successor to the carburetor system, as the latter pointed the way for its improvement by storing the gas under compression in individual reservoirs under each car, whence it was piped to the burners. The Pennsylvania Railroad Company developed this plan, but the illuminating power of gas proved to be considerably diminished by compression; a loss which it was unsuccessfully attempted to restore by mixture with acetylene gas. The "Pintsch system" of enrichment with olefiant gas has since been substituted, in which the gas has been distilled from crude petroleum and is not decomposed by compression.

The Pintsch system originated in Prussia, in 1870, but did not come into general use until the government took over the private lines in 1880–84. By 1900, this system of gas-lighting had been extensively developed in all countries. In Europe alone, it was in use upon 118,000 carriages. Oil-gas loses but little of its illuminating power under compression and can be stored at 90 pounds' pressure under each car in sufficient volume for twenty-four hours' continuous use. Attempts have been made to increase the brilliancy of the light by the use of Welsbach mantles, but with doubtful economy because of breakage. The risk from fire in derailments or collisions has been greatly lessened by strengthening the car-reservoirs, but there is still a possible risk from gas-leakage.

As calcium-carbide became commercially available, its reaction with water furnished an illuminant in acetylene gas, which could be readily produced without the aid of storage gas-holders or a compression-plant. Acetylene gas-lighting was introduced from Canada into this country in 1899, upon the Great Northern Railway. The generator in each car is charged through the roof with 150 pounds of carbide. Water is also supplied through the roof. As it rises up from the bottom of the container to the grating on which the carbide is placed, the latter is slacked and the precipitate drops to the bottom. The gas forms a slight pressure upon the surface of the water, which automatically regulates its production and consumption. There are also a condenser, storage-reservoir and a regulator, to insure pure, dry gas at a steady pressure. The generator is provided with a safety-valve, and, to prevent freezing under the floor, heater-pipes are connected to the covered conduits under the base of the generator; 4.7 cubic feet of acetylene are produced per pound of carbide. Pure acetylene gas can not be compressed without risk of explosion from increase in temperature but, in the Pintsch system, it has been found practicable to use oil-gas mixed with 30 per cent. of acetylene without danger and with doubled illuminating power.

Electric Lighting

As the substitution of the air-brake for the hand-brake prepared the way for the compressed-gas system, so did the substitution of electricity for animal power, on the street-railway, furnish facilities for another system of car-lighting; for electric car-lighting originated on the street-railway, where the current was taken directly from the power-line. Electric lighting on steam-railways was tested experimentally, in 1885, on the London, Brighton & South Coast Railway, on the Northern Railway of France and, in this country, on the Pennsylvania and the Boston & Albany roads. The generator was, at first, operated on the locomotive and afterward transferred to the baggage-car, where it was actuated by steam from the locomotive or by an oil-engine. As the train was deprived of lights when detached from the primary source of energy, electric lighting did not become really practicable until about 1897, when accumulators, or storage-batteries, were placed in each car. By 1905, it had been introduced on the principal lines in Europe and in America.

Where power-plants are available, accumulators may be charged independently of the locomotive. Still, this requires that the cars shall be held at such stations for many hours for recharging. The accumulators were therefore made movable, to admit of an exchange of accumulators before those in use had become exhausted. A further improvement was soon introduced on the Caledonian Railway, in Scotland, in maintaining the lighting-power with current regenerated by mechanism connected by a belt with a revolving axle under the car. Difficulties have been overcome in the adjustment of the voltage and amperage to variations in the speed of the train, and the life of the accumulator is prolonged for a considerable time after the car is detached from the train. A valuable improvement has been effected by the suspension of the generator from the underframe of the car; by this change, nearly a ton in weight is removed from the truck to the spring-borne car-body, with accompanying automatic adjustment of the driving belt to the varying motion of the truck, and with greater facility for inspection. The operation of this system has been found so satisfactory that it has met with general favor.

The "head-end" system of lighting from a generator in the baggage-car was first installed by the Pullman Company, in January, 1887, on the "Florida Special Train," operated from New York to Florida, with accumulators in each car. Even at the present time, this system is in successful operation on the transcontinental lines out of Chicago. In the service to Seattle, over the Chicago, Milwaukee & St. Paul Railway, there are eighteen solid trains of ten cars, each lighted on this system, with an accumulator in the baggage-car, one in the middle of the train and one in the rear car. They are fully charged during the later part of the night and the generator is not operated in the day-time or on heavy grades.

Electric lighting adds to the comfort of passengers by furnishing a brilliant light that may be easily placed for reading, though it can not be so readily graduated as gas or oil can be, when not so required. Its brilliancy may be reduced by the intervention of a rheostat, but with no saving in current; and the simpler device of veiling the light is equally efficacious. The electric equipment is estimated to add nine tons to the weight of each ✓ car. The batteries are self-consuming to an expensive degree and, where they are recharged, to some extent, by a generator on the train, this requires an appreciable draft of power from the locomotive. Electrically-lighted cars can not be used where electric current is not available nor can cars not so equipped be introduced into an electrically-lighted train, save as appendages. The additional expense hardly seems warranted, even as a concession to social efficiency. For the reasons here given, in the present stage of the art of car-lighting, the compressed-gas system is probably preferable from the standpoint of economic efficiency.

Car-heating Improvements. Ventilation. Painting

Car-heating followed the same line of development as car-lighting, from the stage-coach to the railway carriage. At first, travelers relied upon wraps and furs to retain animal heat and then resorted to heated bricks and portable hot-water receptacles. At length, the railway companies themselves supplied such appliances for the first-class carriage compartments, to be exchanged occasionally, as they became cold; and this was where the matter stood on European railways until the central system of car-heating was introduced.

It was not so with American railroads; for here, again, as with car-lighting, the open car suggested a different plan. A stove was placed at one end of the car, with wood as fuel. The wood was gathered up by the brakeman at the wood-racks from which the tender was loaded and piled around the stove, to be supplied at the fancy of the passenger seated nearest to it. The temperature thus regulated by him and by frequent drafts from opened doors, decreased toward zero at the opposite end of the car.

As coal supplanted wood for locomotive-fuel, it was supplied to the car-stove which, for economy's sake, was locked and filled at the will of the brakeman. To save himself trouble, he filled it full and the cast-iron stove was often red-hot, to the inconvenience of those compelled to sit near it and to the general discomfort of all who breathed the vitiated air, thus deprived of oxygen, except as it was regenerated by drafts through opened doors and window-cracks.

This primitive method of car-heating was subsequently replaced by the "Baker heater," by which hot water was circulated through pipes along the sides of the car and under the seats from a boiler inclosed in a closet at one end of the car. Under this system, a more equable temperature was maintained and could be rationally controlled. The heater was, however, objectionable on account of fire-risk from occasional overheating or from its destruction in an accident; though it is still retained, where it is impracticable to utilize a central system.

As the principle of heating an entire train from a single source is only practicable when that source is the locomotive-boiler, its application to such a purpose met with considerable opposition at first. Objections were based upon the draft of power thus diverted from traction, upon the difficulty of securing a uniform system of pipe-connections and other necessary appliances on trains in through-service over different lines and in different countries; as also in heating cars when separated from the locomotive. Profiting by experience gained in establishing uniformity in automatic couplers and in braking-apparatus, uniformity in heating-appliances was more readily secured in this country than in Europe, where central heating only gained recognition about 1905.

Like the central system of car-lighting, the central system of car-heating has originated with the transmission of energy from the locomotive. As compressed air was obtained from the air-pump, steam-heat was drawn from the locomotive-boiler and piped through the train. The defective operation of the earlier appliances was gradually remedied. A circulating system has been evolved in which the return-circulation of steam is maintained by a vacuum-pump on the tender, with drips and taps in the train to carry off the water of condensation. This system satisfactorily provides for the comfort of passengers, yet, like the approved methods of car-lighting, central heating is not so satisfactory from an economic point of view; since either of the two systems in common use makes a heavy draft upon the boiler-capacity and fuel-consumption of the locomotive.

Electric heaters have been successfully introduced into trolley-cars and experimentally on some electrified steam-roads, but as yet electric heating has not reached a point at which it affects car-heating in general.

The heating of a passenger-train is inseparable from its ventilation. The conditions are so dissimilar from those under which ventilation is elsewhere required, as to make it a much more difficult problem. It is an easy matter to change the air in a train in motion, but not so easy to prevent an inrush of drafts accompanied by dust and cinders. Again, the conditions are different in vestibuled cars with closed doors from those in cars whose doors are frequently opened upon uninclosed platforms. Then, too, provision is to be made for cars at rest, as well as in motion.

Ventilation was first practically associated with car-heating in the "Spear Stove" system. Screened hoods at diagonal corners of the car were connected with boxing around coal-stoves. The warmed air was forced by motion of the train through a flue or duct along each side of the car just above the floor, whence it escaped through openings and passed out through the deck-sash. This system of ventilation disappeared with the abolition of individual car-heaters and the advent of central heating, which was enforced by an order of the Interstate Commerce Commission, dated May 19, 1905.

There are now two recognized systems of central heating. One is the direct system of piping along the sides of the car and under the seats; air being supplied through the deck-sash. Dust and cinders are excluded by wire netting, and a violent inrush of air is measurably checked by trailing the deck-sash with the direction of the train. In moderate weather, the change of air is for the most part in the deck-roof and does not adequately descend to the breathing line. In winter, the cold air drops into the body of the car with momentary relief from overheat, but in objectionable drafts. In summer, the movement is not sufficient for good ventilation. This system has been somewhat bettered, as to the deck-sash, by directing the air-currents upward and outward through the roof. It is in use in Pullman cars, and in ordinary service on many roads.

The indirect system originated on the Pennsylvania Railroad, about

1890. In this system, air is introduced through hoods at diagonal corners of the car, as in the Spear-stove system, too high for dust to enter, while the smoke from the locomotive rises still higher or is diverted to the side of the train. Fine cinders, passing through the netting at the intake, fall into a hopper. The air is then admitted into horizontal ducts containing the heater pipes. As it rises thence into the body of the car, it escapes through "Globe" ventilators in the deck-roof; the deck-sash being immovably closed.

It has been experimentally determined that 62,400 cubic feet of air per car per hour can be changed, with all ventilators open, at a speed of 30 miles an hour; from 27,000 to 30,000 cubic feet with ventilators closed; and 23,000 cubic feet in a train standing still and ventilators open. In a standing train, the fresh air may be increased in day-coaches by opening the doors for a few minutes. With steam at 20 pounds' pressure, about 60,000 cubic feet of air per hour is about the maximum volume that can be properly heated, say to 70 degrees, or 1000 cubic feet to a passenger in a sixty-seated car. In a run of 237 miles, in an external temperature of two to five degrees below zero, an internal temperature of 70 degrees was maintained with 30 pounds' steam-pressure, with a radiating surface of 328 square feet in each car. The usual proportion is one square foot for 16.9 cubic feet of volume, and for every 268 cubic feet of fresh air per hour. This proportion must be exceeded in all-steel cars, in which the radiating surface is increased by winding wire around the piping.

The air in a car can be changed every four minutes while the train is in motion but, unless the areas of the intakes and exits are so equalized as to balance the air-pressure, one end of the car will be colder than the other. Moisture in the air, which is essential to proper ventilation, quickly disappears in a close and heated car, and more complaint is caused by improper heating than by insufficient ventilation. To secure efficiency in both respects, a balance of air-pressure must be maintained, with not less than 1000 cubic feet of fresh air per passenger per hour. This result may be attained, some day, by automatic devices, and is only practicable with the indirect system. To heat and waste the required volume of air is a more expensive undertaking than was at first appreciated, and it makes a considerable draft upon the steaming capacity of the locomotive.

Ventilation in a Pullman sleeping-car, with double sash and vestibules, is far more difficult than in open coaches. When the berths are made up and the curtains closed, the movement of the heated currents through the deck-roof tends to draw vitiated air from the smoking-room into the body of the car, where there is an excess of heat and lack of ventilation, and especially in the lower berths. While the train is in motion, these conditions are but partially remedied by wire screens in the windows and cold drafts from the deck-sash that disturb the occupants of the upper berths. The window-screens are difficult of adjustment to the direction of the train and to changes in the external temperature, and it would be an improvement to provide, instead, a ventilating panel in each lower berth that could be manipulated by its occupant. The smoking-room and toilets should be separately ventilated. When sleeping-cars are separated from the train, to stand for some hours fully occupied, the heating system should be fed from a stationary plant, as originated on the Lehigh Valley Railroad; but the resulting overheat and lack of ventilation can only be remedied by the addition of an artificial exhaust, until the car is again in motion. Under exceptional conditions, as in dining-cars and smoking-cars, and in sleeping-cars occupied for some hours before they are taken into train, a forced-draft or blower system, acting through the air-ducts, is especially desirable.

Although the heating and ventilation of passenger-trains, and particularly of sleeping-cars, can not yet be said to have been adequately accomplished, still much has been achieved toward the solution of an admittedly difficult problem, which, as affecting the health and comfort of passengers, may be regarded as an element of social efficiency in railroad transportation, justifying the somewhat extended consideration which has been given to it.[1]

The decoration of passenger-equipment is rather a question of taste and, therefore, of social efficiency; though the use of paint as a preservative is a matter of economic importance. Oil is the preservative element in all paints, and the question of cost must be considered with reference to endurance and lasting qualities, before adopting cheaper substitutes for linseed-oil. The mechanical processes employed in external painting must be carefully conducted, to insure adequate mileage before repainting becomes necessary. Upon the qualities of varnish also depends the frequency with which equipment must be shopped, and the conditions of temperature and dust under which the varnish is applied are matters in which economic shop-efficiency can be displayed. In the selection of painting-materials, attention should be paid to their chemical composition and probable reaction under weather-exposure. This is of equal importance in painting freight-equipment, as is also the choice of colors which should lend conspicuousness for the easier locating of stray cars. The lettering and other symbols of ownership should also be designed with reference to ready identification. The cost of painting freight-cars has been sensibly reduced by spraying the coloring matter with compressed air.[2]

[1] For further information on this subject, see Proceedings of the Master Car Builders Association, 1908; and American Engineer and Railroad Journal, 1908, p. 313.

[2] "Colorizing, a Protective Treatment for Metals," H. B. C. Allison, L. A. Hawkins, Electric Railway Review, July 30, 1915.

"Metallic Preservative Coatings," E. H. Fish, American Machinist, August 26, 1915.

"Painting Iron and Steel," James Scott, Journal of American Society of Mechanical Engineers, August, 1916.

American Inventions

In closing this chapter, it may be noted that four of the most efficient improvements in rolling-stock design are of American origin, — the center-bearing truck, the vertical-hook coupler, the air-brake and the vestibule buffer-platform. The railway passenger-train was originally an assemblage of independent units loosely associated in series, but, thanks to the inventive genius of Janney and Westinghouse, and to the influence exerted by Pullman, it is now a closely-articulated organism, with reliable means of communication throughout its structure. Compressed air constitutes its pneumatic system; its own energy of motion is subservient to its illumination, with individual reading-lamps, electric fans and bell-calls as luxurious adjuncts; while heat is imparted from the locomotive by a circulation akin to that imparted by the heart to animal life through the arteries and the veins.

CHAPTER V

ROADWAY

PART I. SUBSTRUCTURE

RAILWAY LOCATION AND RIGHT-OF-WAY. ECONOMIC ALIGNMENT AND GRADE

THE ways of communication by land between communities are conditioned, as to routes, by their physical and social environment; — physically, as to the topographical features and material resources of the intervening region; socially, as to its density of population and its commercial requirements. In point of economic efficiency, the normal service should be performed with the least expenditure of motive power; therefore, the route should be as nearly straight and level as may be practicable. In point of social efficiency, it should be so located as to provide for the greatest volume of traffic that may reasonably be expected to be accommodated by its construction.

It need scarcely be said that this desideratum of a theoretical minimum of effort combined with an estimated maximum of service is practically impossible. The just mean is to be found in such a compromise of economic and social requirements as will result in a reasonable return from the estimated investment of capital. If the region to be traversed is greatly diversified by mountains and streams, and its material resources are either scanty or scattered, the location of the route should conform to its configuration, subject to the restrictions imposed by the nature of the motive power to be used. But if communication is to be provided between densely populated communities, or for a heavy traffic in commodities produced or concentrated within narrow limits, the cost of construction should be balanced with the cost of operation per unit of transportation, in the establishment of the horizontal and vertical alignment of the route.

In modifying the topographical environment of a community, in order to facilitate its means of communication, the engineer does not deal with human passions and emotions nor with metaphysical abstractions, but with concrete facts. These he must mold in accordance with physical principles which he cannot control and to which he must conform, regardless of preconceived opinions or of personal predilections. The efficient location of a commercial highway should, therefore, be preceded by such knowledge of the topography, climate, material resources, population and commercial conditions of the region to be traversed, as will enable a reasonable compromise to be made between its physical features and its social requirements.

Soon after the line has been provisionally located, options should be secured for the right-of-way. It is better to pay well for a title in fee-simple than to accept a mere easement, even as a gratuity. Wherever practicable, the width should not be less than one hundred feet. Through wild lands, a width of two hundred feet may often be obtained at a nominal cost. In course of time, the wisdom of this course becomes apparent in freedom from local interference and in saving subsequent land-damages, as business development shall require additional elbow-room. Until so required, the outer zones through wooded lands may remain in forest, and the open land may be leased to adjacent farmers. The right-of-way notes should be recorded at once in permanent form, the metes and bounds carefully established and prominently marked, and the titles duly registered. Inattention to these matters, while the details are fresh in the minds of all interested, has often resulted in tedious litigation at heavy cost.

On any line of considerable length, its ruling gradient is not determined by the relative altitude of its termini, but by the rise and fall of the country which is to be traversed. If there be any intervening mountain range, the ruling gradient is to be determined by the relative cost of surmounting that range, either by developing the line in length, by tunneling or by the introduction of exceptionally heavy gradients at critical points. The cost of construction in either case being approximately equal, exceptional gradients may serve to keep the ruling gradient down elsewhere, with subsequent economy in operation, where the traffic is in heavily loaded trains. For if, thereby, the normal train-loads over the rest of the line may be increased by even a small percentage, the cost of assisting such trains over the critical grades will add but slightly to the general cost of the service. In the location of a line across an existing line, it is advisable, wherever possible, to bring the new line parallel to the other for a considerable distance on each side of the intersection, with station-platforms between them. This plan facilitates transfers and track-connections, and also gives a better view of trains approaching the crossing.

Of the two departures from a right line between termini, whether vertical or horizontal, the latter is of less importance economically and may be of great advantage socially, where divergence is required to reach centers of considerable traffic. A divergence of ten miles to the right or left of the middle of a line a hundred miles in length, adds but two miles to the total distance and inappreciably to the cost of operation. Nor are long tangents of material advantage. A line may profitably conform to the topographical features of a region by frequent curves separated by short tangents.

There are, indeed, some advantages in operating over long tangents, by decreasing the risk of collisions or derailment, when emergencies occur in train-service; but, as a general rule, the saving of distance by the preservation of long, straight reaches of line does not justify any considerable addition to the cost of construction. The cost of operating additional mileage does not add materially to the total cost per transportation unit. This is evident from a comparison of the cost, in this respect, of the several lines between New York and Chicago; as, for instance, on the New York Central line, which runs due north for 150 miles before trending westward, without affecting its importance as a through line to the West and with its traffic largely increased from the trade-centers that it serves by reason of this divergence.

The vertical alignment of any highway must conform to the mode of transportation to be utilized upon it, whether it be a mountain path for porters only, or a trail for pack-animals, or a macadamized turnpike for stage-coaches. In any of these cases, it is conditioned by vital energy and by muscular power. But with a railway, it is a matter of mechanical power and of adhesion to the rails. The cost of train-service is more unfavorably affected by operating over frequent changes of grade, within the limits of the ruling-gradient, than over a long ruling-gradient continuously to a summit; since no economic purpose is served in successively surmounting the intervening elevations on a longer route. Inconspicuous breaks of grade, though slightly diminishing the cost of construction, may therefore seriously affect the operating value of a railroad location. Changes of grade should be connected by vertical curves of sufficient length to relieve the shock to a long and heavy train as the slackened draw-gear is stretched by the application of steam to the locomotive.[1] On a straight line, under

[1] The effect of intermediate changes of grade, or of "undulating" grades, varies with the acquired momentum of the train as it approaches an ascending grade. In the case of an ordinary passenger-train approaching upon a level a series of undulating grades of one per cent., or 52.8 feet per mile, at a speed of 50 miles an hour, its acquired momentum may be assumed as equivalent to a "potential lift" of 88.75 feet before coming to a state of rest. At a summit, one mile distant, there would still remain a potential lift of $88.75 - 52.8 = 35.95$ feet, corresponding to a speed of about 33 miles an hour on a level, without additional power from the locomotive. If the next descent be 0.6 mile, and 31.7 feet fall, the additional momentum due to the acceleration on the descent would result in a potential lift of $35.95 + 31.7 = 67.65$ feet, corresponding to about 44 miles an hour. On the next ascent of 0.4 mile, a rise of 21.12 feet, the train would arrive at the summit with a remaining potential lift of $67.65 - 21.12 = 46.53$ feet, corresponding to a speed of 36 miles an hour. The effect of this series of undulating grades upon the performance of the train, for this distance, would be to reduce its speed from 50 miles to 36 miles an hour with an absolute rise of 52.8 feet, without additional power from the locomotive. Assuming that the changes of grade were connected by suitable vertical curves, there would have been a uniform pull upon the drawbar of every car in the train, and consequently with no jerking effect upon the passengers. See "Economic Theory of Location of Railways," A. M. Wellington, page 348.

favorable conditions, a locomotive may ascend a gradient of 1 in 22.5 by adhesion alone, though the theoretical limit is about 1 in 16, or 330 feet to the mile. On such a gradient, its economic efficiency would be *nil*, as it could exercise no tractive power at the tender-drawbar.

Inclined Planes and the Rack-rail. Ruling Gradient

Inclined planes were frequent features of English tramway construction, following upon the use of steam hoisting-engines in the collieries. The maximum gradient for animal power was between 25 and 30 feet to the mile, and this limit seems to have been as much determined by the difficulty in controlling the speed of the loaded cars on the descent as in maintaining the average efficiency of animal traction in the opposite direction. Where this controlling gradient could not be preserved, resort was had to inclined planes. There were several double inclined planes on the Stockton & Darlington Railway. Although locomotive traction had by that time attracted much attention, the practical value of the principle of adhesion had still to be tried out, and it was seriously proposed to operate the Liverpool & Manchester Railway by a continuous series of double inclined planes, in twenty-one sections, in the total distance of thirty-two miles. It was to decide this matter, that the celebrated Rainhill competitive tests were made, in which the victory of the "Rocket" opened up a new era in railway traction.

Railway construction in the United States underwent a similar development. There was an inclined plane on the Quincy tramway. The tramway of the Delaware & Hudson Coal Company ascended the Lackawanna Mountain with a rise of 800 feet in 3½ miles by inclined planes of 1 in 12 and 1 in 20. The Mauch Chunk road was also an early example of tramway operation by animal traction, in connection with a series of inclined planes.[1] Inclined planes were retained in steam railway construction. On the Baltimore & Ohio Railroad, as originally located, there was an inclined plane, 41 miles from Baltimore, ascending 80 feet in 2150. A second plane ascended 100 feet in 3000. From the summit, 813 feet above sea-level, the line descended by one plane of 160 feet in 3200 and by another 81 feet in 1900.

On the Mohawk & Hudson Railroad, opened August 9, 1831, the ascent of 185 feet from the Hudson River to the upper level in Albany, was operated by a twelve-horse-power engine. On the Portage Railroad in Pennsylvania, built over the Alleghanies in 1834, there was for thirty-six miles a succession of ten inclined planes, operated until 1853 by engines of thirty-five horse-power at a rate of four miles an hour. The summit was 1398

[1] See Appendix IV, Table IX.

feet above the eastern canal-basin, 1171 feet above the western basin and 2311 feet above sea-level. The longest plane was 3116 feet with a rise of 307 feet. At the Columbia end of the Philadelphia & Columbia Railroad, opened October 7, 1834, there was an inclined plane rising 90 feet in 1800, and at the Schuylkill terminus, one of 196 feet in 2800, or 369 feet to the mile; the intervening maximum gradient being 44 feet to the mile. This inclined plane was the scene of a notable performance on July 9, 1836, when a locomotive, built in Philadelphia by William Norris, ascended it in two minutes. This exploit was so unprecedented that the announcement was received with incredulity, until it was repeated ten days afterward in the presence of an officially appointed commission, and was subsequently commented upon by European engineers.[1] A locomotive of the "Camel" type (0–4–0), built by Ross Winans, was operated on a temporary track over the Kingwood Tunnel on the Baltimore & Ohio Railroad, on a grade of 530 feet to the mile, hauling one car-load of material at a time. Practically, the ruling gradient rarely exceeds 52.8 feet to the mile. In exceptional cases, this may be exceeded and the normal train assisted at such points by "pushers" or "bank-engines."

Gradients beyond the limit of adhesive traction may also be ascended by means of the rack-railroad. A cog-wheel or pinion engaged in a toothed rack on the track was patented in England in 1811. In 1812, a locomotive on this plan hauled coal from Middleton to Leeds, a distance of 3½ miles. A half-century later, Sylvester Marsh adopted this system for the Mount Washington Railroad in New Hampshire, on a gradient of 1 in 2½. The rack had pin-teeth cut in angle-bars. In Switzerland, there has been a considerable development of the rack-railroad on the Abt system. This system consists of a multiple-rack, its sections laid side by side, with the teeth breaking joints or "staggered," so that the driving-wheels are constantly engaged with the rack; the rack combined with adhesion working on steep grades, and adhesion only on easier ones. The system has been specially adapted to mountain-roads engaged in excursion-traffic. The Mount Pilatus Railway, near Lucerne, is operated on a gradient of nearly 1 to 2 by a double rack with vertical teeth on each face. The Jungfrau line has teeth cut in the head of a T-rail.

In England, the ruling-gradient is generally much easier than in the United States. On the Liverpool & Manchester Railway, it was 1 in 900, except on the inclines in Liverpool and at Rainhill. On the Great Western Railway, it is 1 in 1320 for a long way out of London. One of the steepest

[1] The locomotive employed on these occasions was of the following dimensions: cylinders, 10¼ inches diameter by 17⅝ inches stroke; driving-wheels, 4 feet in diameter; truck-wheels, 30 inches; 78 tubes, 2-inch diameter by 7 feet long; weight on driving-wheels, 8700 pounds; total weight, 14,930 pounds; trailing load, 31,270 pounds. With 80 pounds' steam-pressure, the ascent was made in 2 minutes 24 seconds. "When Railroads were New," C. F. Carter.

gradients, on the Midland Railway between Birmingham and Gloucester, is the Lickey incline, which is 1 in 37 for two miles.[1]

The restriction of the vertical alignment by the ruling-gradient affects also the horizontal alignment. To keep within this limit, advantage is taken of the work which has already been performed by water-courses in excavating valleys and ravines in mountain-slopes and hill-sides. Here the value of the practiced eye of the experienced locating engineer is seen in fitting the line to the face of the country.[2] The summit is generally to be sought in a mountain-pass or gap, and the line can usually be developed in sufficient length to attain this elevation without exceeding the ruling-gradient. In some cases, this purpose can only be accomplished by resort to unusual expedients, such as the spiral tunnels on the St. Gotthard Railway, or on the lines through the Rocky Mountains; or else by zig-zags or "switch-backs," as on the line from Bombay up the Ghauts to the interior plateau of Hindustan.[3]

An early example of this method of overcoming excessive elevation in railroad construction is the Mauch Chunk Switch-back.[4] Other instances may be cited, though of a temporary character. The Baltimore & Ohio Railroad was operated for some time, in 1852, over the Broad Tree Tunnel, near Wheeling, by a switch-back, 2¼ miles in length, with grades of 293 to 340 feet to the mile. In 1878, the Atchison, Topeka & Santa Fé Railway crossed the Raton Summit by a switch-back, 3¼ miles in length, with six switches, on a maximum grade of 316 feet to the mile, with Mogul locomotives weighing 110,000 pounds.

Effect of Curvature

In balancing the relative effect of gradient and curvature upon the assumed normal train-load, the maximum permissible degree of curvature should not coincide with the ruling-gradient. The resistance due to curves alone, under ordinary conditions, is based on the assumption that each

[1] Classification of Usual Gradients

	English	American
Heavy	1 in 100	1 per cent. or 52.8 feet to the mile
Moderate	1 in 200	0.5 per cent. or 26.4 feet to the mile
Easy	1 in 400	0.25 per cent. or 13.2 feet to the mile

[2] Between Philadelphia and Harrisburg, on the Pennsylvania Railroad, the old line constructed by the State is crossed every half-mile, for long stretches, by the new line which, though never more than a few hundred feet away, has hardly one-tenth of its curvature. "Economic Theory of Location of Railways," A. M. Wellington.

[3] An extended discussion of the relative efficiency of inclined planes, spirals and switch-backs will be found in "Railway Location," by A. M. Wellington, 1915, Chapter XX.

[4] See Appendix IV, Table IX.

degree of curvature equals a straight gradient of 1.5 feet to the mile. Curves of six to ten degrees do not limit the speed of fast trains nor materially lessen train-loads, but a tangent of not less than four hundred feet should be secured between such curves for easing the entrance and departure of trains by the intervention of transition-curves. On a level line, consolidation locomotives take 80 or 90 cars around 8 and 10 degree curves at 15 miles an hour. They are operated with ease around 14 to 16 degree curves and are in general use on roads with even heavier curves. Transition or easement curves are introduced between heavier curves by extending the curvature farther back on the tangent at a gradually decreasing rate.[1]

The average horizontal alignment of roads in the Mississippi Valley and in the Southern States is comparatively straighter than in the East. The percentage of level line is, however, somewhat greater in the East. In the Rocky Mountain region, the Central Pacific line of 872 miles averages 52 per cent. curvature per mile, of which 105 miles average 151 degrees. On the Colorado Central Railroad of 34 miles, the average curvature is 420 degrees per mile.[2]

On the early English lines, there were no curves of more than one degree, but subsequently curves of two and three degrees were used. In Holland, of a total mileage of 945 miles, 62 per cent. is level and but 27 miles are on gradients from 0.5 to 1.5 per cent. In Germany, 25 per cent. of the mileage is between these gradients and a little over 25 per cent. is curved; while in Norway, with 50 per cent. of curved line, 37.5 per cent. is between the same gradients.

[1] Simple curves are described with a single radius; compound curves, with two or more radii. Reverse curves are curves of contrary flexure, usually separated by a short tangent. In England, the radius is expressed in chains of 66 feet; in the United States, by the angle subtended by a chord of 100 feet, which is the length of the chain used in this country. Curves of over 8° are usually run in with 50-foot chords and those over 16° with 25-foot chords. The radius of a 1° curve is 5730 feet or nearly 87 English chains. The radius of any sharper curve may be obtained by dividing 5730 by the degree of curvature. This is correct up to an 8° curve. The equation of gradients per degree of curvature varies with the character of the traffic; 0.02 per cent. being commonly used for light curves and for freight-tracks where the speed is slow, and 0.05 per cent. for very sharp curves. For table of curve-equations, see "Railway Location," Wellington, page 652.

[2] AVERAGE ALIGNMENT OF RAILROADS IN THE UNITED STATES IN 1880

Region	No. of Lines	Miles of Line	Curvature			Per Cent. Level Line
			Curves per Mile	Per Cent. of Curvature	Degrees per Mile	
Eastern . .	99	5372	1.88	35.5	55.9	22.8
Western . .	49	8558	0.78	16.9	16.9	21.4
Southern . .	17	3511	1.10	27.6	31.5	22.0

"Railway Location," A. M. Wellington.

An illustration of original location in conformity with the principles of economic operation is afforded in the extension of the Lehigh Valley Railroad through New Jersey from Phillipsburg to Perth Amboy, under Robert H. Sayre, Chief Engineer. Although this line incidentally furnishes an entrance into Jersey City, the chief purpose in its construction was to provide for coal-traffic to tidewater. This purpose is accomplished by virtually concentrating all intermediate differences of elevation at the summit in Musconetcong Tunnel, 12.5 miles from Phillipsburg, on an ascending grade of 22.0 feet per mile, thence descending for 6.5 miles on a 47.5 feet per mile ruling-gradient to a point 150 feet above sea-level. The remaining 40 miles to tidewater is virtually a gentle descent, broken by slight changes of grade at railroad crossings. As a consequence, unbroken trains of 50 cars, weighing gross 3300 tons, are handled to tidewater over an intervening elevation of 255 feet, assisted by only one pusher for 12 miles from Phillipsburg to the summit. Trains of 70 empty cars, weighing 1260 tons, are assisted for 7 miles to the summit by a single pusher. The coal-traffic over this line for the years 1910–1914, has averaged annually 2,131,525 tons.[1]

Railway Construction

Though the railway, or railroad, has given its name to the system of transportation that now dominates all traffic by land, its inception antedates the advent of that system by two hundred years, originating merely as an improved road-surface, just as macadamizing superseded stone-paved highways; and it is only of late years that it is really becoming a more integral part of the roadway itself. In fact, the railway proper is still superimposed upon the highway, and so the two may be separated in a discussion of railway efficiency. Thus disassociated, as superstructure and substructure, the latter is really the "permanent way," for there is little permanency in the superstructure. Ballast, timber, rails and fastenings are all transient elements of the superstructure, and, from this point of view, attention may first be given to the substructure or "permanent way."

In England, the permanent way was modeled upon the construction methods developed by Telford and by Macadam in the early part of the

[1] Lehigh Valley Railroad. — Phillipsburg to Perth Amboy

	Elevation above Sea-level. Feet	Changes of Elevation	Miles	Total
Phillipsburg . . .	217.0			
Summit	472.0	+255.0	12.38	
Lansdowne . . .	181.3	−290.7	6.52	18.90
Bound Brook . .	31.4	−149.9	24.60	43.50
Raritan Junction .	98.0	+ 66.6	13.30	56.80
Perth Amboy . .	31.5	− 66.5	2.80	59.60

nineteenth century. Between 1818 and 1829, over one thousand miles of turnpike road of this character had been built in England. These roads rivaled and surpassed the ancient Roman roads in solidity, and in the design and execution of viaducts and auxiliary structures. Their alignment and gradients were skillfully adapted to the topographical contour of the environment, and, in all these respects, the experience of the highway engineers of that period was equally valuable when directed to railway construction.

With ample capital at their disposal and with growing experience, the English railway engineers undertook works of increasing magnitude, in which they developed improved and novel methods of construction and design. The railway alignment was adapted to mechanical traction by easier curvature and by lighter gradients, sometimes at great expense for heavy earthwork, viaducts and tunnels. Because of the attention given to these matters in the original construction of English railways, but little alteration in their permanent way has since been necessary to meet the increased requirements of traffic, and the same thoroughness of execution marked all of the accessory structures.

From time immemorial, the excavation and embankment required to bring the surface of a highway to the desired grade have been performed by manual labor, long assisted only by the pick, shovel and hand-barrow. In the fifteenth century, the labor of this character was somewhat lightened by the invention of the wheelbarrow, which continued to be the main reliance for short hauls until it was supplanted, under favorable conditions, by the horse-shovel or scoop. For longer hauls, the contractor's track-equipment has replaced the dump-cart; but the chief appliance in expediting earthwork, and in reducing its cost, is the steam-shovel. By its superior capacity and speed of operation, it is now practicable to lengthen the average haul and the consequent balancing of earthwork between cuts and fills, before resorting to borrowing or wasting material. A man shoveling gravel or light soil ought to handle about 10 cubic yards in a day of ten hours. An ordinary railroad steam-shovel of 70 to 90 tons, under similar conditions, should handle at least 1000 cubic yards, at a cost of about $50.00. Compare this result of mechanical energy with that of vital energy.[1]

Gunpowder, invented for destructive purposes in warfare, has been equally powerful for similar purposes in highway construction. Gradually, it has been superseded by blasting powder and by other explosives better suited for work of this character. The slow process of drilling blast-holes by hand has been displaced by appliances operated by steam, by electricity or by compressed air, which have served greatly to diminish the amount

[1] Capacity of Excavating Appliances. Barrow, 2 cu. ft. Drag scraper: No. 1 — 5½ cu. ft. No. 2 — 4½ cu. ft. No. 3 — 3½ cu. ft. Wheeled scraper: No. 0 — 7 cu. ft. No. 1 — 9 cu. ft. No. 2 — 12 cu. ft. No. 2½ — 14 cu. ft. Steam-shovel bucket, 1 cu. yd. (minimum).

of manual labor and to shorten the period of execution where work is carried on in material too hard to be broken up either by the pick or by the steam-shovel.

Earthwork construction often involves operations of great magnitude, as to quantities of material to be moved, yet, save in the particulars just mentioned, it affords but little opportunity for advance in engineering efficiency. A road-bed built with due regard to the natural slope of the materials of which it is composed is virtually imperishable, so long as its slopes are protected by careful sodding or by other suitable precautions, and its foundation is kept secure by adequate drainage.

Much difficulty is experienced at times in obtaining a stable foundation for an embankment on treacherous soil. A notable instance occurred in the construction of the earliest railway intended for general traffic, the Liverpool & Manchester Railway. The line, as located, crossed a boggy tract, known as the Chat Moss, for four-and-a-half miles. The foundation proved to be of saturated, peaty matter from ten to thirty feet in depth, resting on a clay and sand subsoil. An embankment of 277,000 cubic yards in content consumed 670,000 yards of material and was only completed by virtually floating it on the bog.

Such treacherous foundations are sometimes encountered unexpectedly. In one instance, the line ran rather diagonally for some distance across an open marsh, through which there trickled an insignificant stream. As the embankment was extended, it settled so much that a temporary trestle-work was built to carry on the work. At one point, a pile went out of sight at the first blow, and the hammer with it. Two pilings, each sixty feet in length and doweled together were required to reach a solid foundation. As the work went on, it appeared that the meadow occupied the site of what had been a deep water-course, whose meanderings crossed the line in several places. After losing a large quantity of filling, recourse was had to a floating foundation of long saw-mill slabs, crossed in alternating layers, upon which the material had to be carefully distributed to prevent it from breaking through the natural surface and capsizing.

Intercepted water-courses must be passed through the road-bed, making the openings of ample cross-section, to provide for abnormal floods. Across small streams and in low embankments, the culverts may be left open, or, in high banks, arched over with masonry, constructed in advance of the earthwork. In some cases, tubes of heavy earthenware may be advantageously employed, in sections alternately inserted in each other, so that the water may flow over and not against the inner joints. At open culverts, the ends of the bank should be carefully protected against wash-outs, the upper ends of covered culverts protected against seepage through the embankment, and their lower ends against undermining by the outfall of flowing water. Such culverts may also be constructed of iron tubes, plain or corrugated.

Viaducts and Trestles

If the grade-line be projected above the natural surface beyond the height within which earthwork may be economically employed, resort is had to viaducts. At an early period in ancient history, such structures served a useful purpose in providing water for fortified places. The several aqueducts which supplied Rome at the height of its power, still fulfill that object to some extent, or stretch in ruined arches for miles across the Campagna. Elsewhere throughout the Empire, similar monuments bear witness to the skill of Roman engineers.[1] Viaducts were unnecessary while traffic was borne by porters or by pack-animals; it was only after wheeled vehicles came into general use that excessive gradients were found objectionable in highway building, and more especially when engineering practice was directed to railway construction.

In viaduct-work, as distinguished from bridge-building, the length of the spans is governed by an adjustment of the balance between the relative cost of the foundations, piers and connecting-superstructure, according to the character of the available building-material and the nature of the soil. Any advantage that may be derived from increasing the height of the grade-line, is but little diminished on account of the accompanying cost for increasing the length of the supporting-piers. The cost of the abutments and of the floor-system is practically independent of the length of span. The cost of the piers depends mainly on the character of the soil and on the height of the grade-line. In a viaduct with many arches of long span, large quantities of material are required to fill in the spandrels in order to resist the tendency to deformation at the haunches. As masonry-work of this kind fulfills no structural purpose, it is more economical to substitute trussed girders on piers. For any given load and type of superstructure, the cost of the girders for one span varies nearly as the square of the span-length, and the total cost is least where the cost of one pier equals the cost (erected) of the main girders over one span.

The simplest type of a railway viaduct, the wooden trestlework, was generally adopted in early construction in the United States, wherever timber was abundant. The bents, on a low grade-line, might be merely two piles, capped and placed ten feet apart, carrying simple track-stringers extending over two bents and jointed on alternate bents, the whole structure connected by mortises and tenons, pinned with draw-bore. The stringers were jogged vertically and pinned to the caps. On a grade-line up to ten or fifteen feet above the natural surface, the bent was often temporarily of three piles, braced by planks spiked diagonally across

[1] Pont du Gard. — Aqueduct carried for 820 feet on three tiers of arches, the two lower tiers from 60 to 75 feet span. Segovia. — Aqueduct 2410 feet long, 109 arches in two tiers, 102 feet high. Mainz. — 2100 feet long, on between 500 and 600 piers. Antioch. — 700 feet long and 200 feet high.

them. When the piles began to decay, they were cut off below the line of permanent moisture and a framed bent was then erected upon them. On a dry soil, the framed bent often rested on mud-sills. On a still higher grade-line, the bents assumed the character of piers, spaced farther apart and carrying trussed stringers. Very lofty viaducts so constructed became pyramidal structures of framed timber, and others of similar design were subsequently built of iron beams and columns.[1]

In any system of trestling over ten feet in height, the bents should be braced transversely and diagonally in each additional height of ten feet, as well as transversely in the floor-system and by longitudinal braces or walings. The floor-system should be substantially constructed, with heavy guard-timbers lined with iron plates on the track-side. Safety in train-service would be further insured by placing a re-railing device at each end of every viaduct and bridge with an open floor.

Iron viaducts are usually spaced in 30-foot spans, with double bents braced in pairs; though they are also built in spans of 45 to 60 feet, to suit local conditions. The cost per linear foot is thereby but little affected, as a heavier floor-system is required with increasing length of span. One of the earlier examples in Europe is at Freiburg, Switzerland, built in 1862 and still serviceable. It is double-track, 225 feet in height and 1100 feet in length. The early American viaducts of iron were of slighter construction. Several have proved insufficient for the increasing service to which they were subjected, and have been replaced by more substantial structures.

The Kinzua Viaduct, on the Bradford division of the Erie Railroad, was single-track, built in 1880–1881, 2053 feet in length; and was composed of twenty towers, varying in height from 30 to 285 feet, from top of masonry to top of ties, with a batter of one to six. On account of its height and manner of construction, it vibrated under the passage of trains to such an extent that speed over it was restricted to five miles an hour. It was replaced, in 1901, by a structure of somewhat novel design, built upon the original masonry. The details and dimensions are the same in all the towers from the top downward. The height of the stories is 62 feet, subdivided longitudinally by bracing, but without diagonal bracing within the tower. The latticed columns, composed of plates and angles, measure 37 inches, transversely. The intermediate transverse struts are box lattice-girders, respectively 4, 6, 7 and 8 feet in depth. The longitudinal diagonals are built of two lattice-channels, connected by diaphragms at their intersections and with the columns. The only longitudinal struts

[1] The Portage Viaduct carried the Erie Railroad over the Genesee River at a height of 250 feet, across a chasm 900 feet wide, in spans of 50 feet; and was built in two years of 16,000,000 feet of timber at a cost of $175,000. It was opened on August 9, 1852, destroyed by fire in 1875, and replaced in forty-seven days by a bridge of steel. "When Railroads were New," C. F. Carter.

are at the bottom of the tower. The tower-legs are bolted to the masonry by two 1½-inch bolts. The floor is carried by plate-girder deck-spans, 9 feet between centers; upon each tower they are 38 feet 6 inches in length and 4 feet 6 inches in depth. The intermediate spans of 61 feet are 6 feet 6 inches in depth. The total weight of the deck-spans is 638 tons; and of the towers, 2715 tons. Expansion is provided for by twelve freely-moving girder-ends on friction-rollers. The change in length of the track-stringers, due to a range of temperature of 75° F., is about ten inches in the length of the structure. The work of erection was carried on from each end by a traveler, spanning 160 feet, having an old tower in the middle. The work consumed four months with 120 men.

Viaducts of trestlework, up to twelve and fifteen feet in height and several miles in length, were common where railroads were built through the cypress-swamps that border the streams along the South Atlantic coast. Since the introduction of reinforced concrete, these timber-structures are being in many instances replaced by an iron superstructure on concrete piers, or by a series of low arches carrying an embankment. Viaducts of imposing dimensions are also constructed of reinforced concrete.[1] The viaducts on the Florida East Coast Railroad are of an even more ambitious character. The extension of this line to Key West is built for some sixty miles along the low-lying range of islets forming the Florida Keys. The numerous intervening channels are crossed by viaducts of reinforced concrete piers and steel superstructure. One of these, the Long Key Viaduct, is 2½ miles in length, with arches of reinforced concrete in 50-foot spans and 30 feet above low tide. In this region, where there is neither building stone nor brick-clay and where the sea is infested with teredo and limnoria, this extension would have been impracticable but for the use of reinforced concrete.

Bridges. Early Types

Deeper water-courses must be spanned by bridges, and in designing such structures engineering efficiency of the highest order has been displayed. Bridge-building was a development of house-building. Where building-stone was abundant, or clay suitable for brick-making, the mason became the bridge-builder, and the arch which supported the wall over door or window openings was a fundamental principle in bridge-construction in

[1] The "cut-off" opened for traffic in November, 1915, between Clark's Summit and Hallstead, Pa., on the Delaware, Lackawanna & Western Railroad, includes two remarkable viaducts of reinforced concrete. Tunkhannock Viaduct, 2375 feet in length and 242 feet above the bed of the stream, includes ten spans of 180 feet each and two of 100 feet. The double-track roadway is carried by a series of stilted arches of shorter span, superimposed upon the longer spans. This viaduct contains 167,000 cubic yards of concrete and 1140 tons of steel. The Martin's Creek Viaduct is 1600 feet in length and 150 feet above the bed of the creek.

the time of the Roman Republic. The economic limit for masonry-arches was about a hundred feet span; where timber was plentiful, the carpenter replaced the mason, the principle of the rafter or beam superseding that of the arch.

In its simplest form, the span of the timber-bridge was limited by the dimensions of the available timber and by the weight of the normal passing load. If the beam was of sufficient length to span the opening, but was of insufficient cross-section to carry the load, engineering genius provided the remedy. The strain at the middle of the girders that supported the floor-beams was partially relieved by erecting a king-post at that point and bracing it against the ends of the girder, thus transferring the strain by compression to the abutments. Where the span was so long as to require a king-post of excessive height to give the bracing the proper angle, an alternative plan was to divide the length of the girder by two queen-posts connected by a tie-beam or strut, thus carrying the strain through the braces to the abutments at the required angle. Still another method was to place the king-post or queen-posts beneath the girder, supported by an iron rod strained over their ends, by which the stress from the passing load was transferred to the abutments by tension instead of by compression. Both of these methods, it will be seen, were borrowed from roof-carpentry.

The next advance in timber-construction was to cover a span exceeding the length of a single beam by bolting several together with lapped joints, and then combining the methods of compression and of tension in a single trussed girder. The many designs of this type may be classed either as paneled trusses, in which the stresses are concentrated at widely separated points in the upper beam, or top-chord, and in the lower beam, or bottom-chord; or else as lattice-girders, composed of many braces and counter-braces bolted or pinned together at every intersection, forming a web which is connected with the chord-members at many points. The trussed girders, with their top-chords and bottom-chords respectively connected by lateral bracing, virtually form a box girder, which may carry the floor-beams either on the bottom-chords, as an overgrade or "through" bridge: or on the top-chords, as an undergrade or "deck" bridge. In the latter case, the interior of the bridge is stiffened by cross-bracing against swaying under a passing load. Where the grade-line is at a sufficient distance above high-water level, a considerable saving in the height of abutments or piers may be made by carrying the roadway on the top-chord. By connecting the trusses continuously in a bridge of three or more spans, a theoretical advantage may be obtained of 49 per cent. in dead weight and of 16 per cent. in the live load.

Timber-arches were used as early as 104 A.D. in the bridge built over the Danube by order of Trajan and, in the longer spans of later design, the increased stresses were resisted by a combination of panel trusses with arches built of beams. By the middle of the eighteenth century, the art of building truss-bridges had made great advances in Europe. A bridge was then built over the Rhine at Schaffhausen with spans of 172 and 193 feet. It was constructed in panels with vertical posts, the stresses at the middle of the top-chords being transferred by long braces and connecting tie-beams through the end-panels to the piers and abutments. The same engineers built the Wettingen Bridge of 390 feet span, which was the longest timber-span ever constructed. As suitable timber became scarcer and the supply of iron ampler, the principles of construction, developed by working in timber and stone, were applied to the use of metal also. Wrought-iron was used in combination with timber, or with cast-iron posts or struts, and arched bridges were built, principally of cast-iron.[1]

The superior efficiency of wrought-iron over timber, when used in tension, was more fully exhibited in connection with an entirely different principle of construction, — that of suspension. This principle had been put in practice anterior to historical dates in the rope-ferry and for foot-bridges over mountain-gorges. In the latter part of the eighteenth century, it was applied to highway-bridges; the roadway being suspended from parallel chains stretched over the span, strained at the abutments over lofty piers and anchored in masses of masonry. Wire cables were subsequently substituted for chains. In 1810, Telford built a bridge over the Menai Strait of 570 feet span, which was suspended by iron bars linked together. This was followed by a suspension bridge of 870 feet span at Freiburg, Switzerland.

Such was the state of the art of bridge-building when it was applied to railway construction in England. Arched bridges continued to be used for moderate spans under a high grade-line, but, where a lower grade-line left no room beneath it for an arched bridge, the opening was spanned by girders on piers. Long spans in highway bridges were practicable because the normal loads bore so light a proportion to the weight of the bridge itself, that their added strains were a negligible element in a bridge-design. But, with the development of railway transportation and the demand for heavier loads at high speeds, this was no longer the case, and engineering skill was called upon to meet this exigency.

Tubular Bridges

In 1845, a plan was required for carrying the Chester & Holyhead Railway over the Menai Strait, already crossed by Telford's highway bridge of 570 feet span. The work was intrusted to Robert Stephenson and William Fairbairn. The coefficients of the strength of materials com-

[1] Early cast-iron bridges: Coalbrookdale, over the Severn, 1773–1779, 100-foot spans of five cast-iron webs; still in use. Wearmouth, 1793–1796, arches of cast-iron voussoirs. Southwark, over the Thames, 1814–1819, center span of 241 feet and rise of 24 feet, of cast-iron ribs. Paris, over the Seine, 1800–1806, and 1834–1836.

monly used at that time were largely empirical, as were also the formulas in which were expressed the inherent stresses in structures and the occasional ones to which they are subjected from moving loads. The principle of construction that was adopted was that of the girder. Girder-bridges of short spans had already been constructed of iron in the form of a box, and the box-girder type was made the object of experiments in which the proper functions of the top and the bottom-chords of a girder and of the web connecting them were for the first time definitely determined and reduced to formulas by the eminent physicist, Eaton Hodgkinson.

As a result of these experiments, the Conway Bridge was designed as a pair of box girders of rectangular section, each large enough for the passage of a train through it. The top and bottom were of cellular construction, connected by sides of heavy plates stiffened by ribs and gussets. This bridge gave such satisfaction that the design was repeated in the Britannia Bridge, over the Menai Strait, as a pair of continuous tubular girders.[1] The material was assembled on the adjacent shore; the girders were floated to the bridge-site and raised into position by hydraulic appliances.

Soon after the completion of the Britannia Bridge, Isambard K. Brunel built the Saltash Bridge, near Plymouth. In the principal spans, the top-chord was a single "lenticular" arched tube, and each bottom-chord was a pair of chains composed of pin-connected links, suspended by hangers from the outer edges of the wide top-chord. The trusses from which the roadway was suspended were therefore parabolic in form, the idea being so to dispose the material as to offer the greatest resistance to the strains to which it was to be subjected, with the least practicable dead weight.[2] In designing this bridge, Brunel displayed that independence of precedent which distinguished his genius also in the adoption of a seven-foot gauge for the Great Western Railway, and in the construction of the steamship *Great Eastern*.

The Britannia Bridge marked the advance in engineering efficiency, due to the demand for heavier loads at higher speeds in railway transportation, which raised bridge-building from an art to a science. Yet, notwithstanding the recognized ability of the engineers who planned it, the tubular girder has only been repeated, by Stephenson himself, in the

[1] The Britannia Bridge, completed in 1850, was composed of two clear spans of 460 feet each, and two of 230 feet each, 104 feet above high water. The tubular girders were 1511 feet in length, 15 feet wide, 23 feet deep at the ends and 30 feet at the center; each girder weighed 4680 tons. Forty per cent. of the total weight of the girders was in their stiffened sides. Proportion of depth to span, 1 in 16. Encyclopædia Britannica.

[2] Saltash Bridge: Two spans of 455 feet each, and seventeen shorter spans. Top-chord, a lenticular tube, 17 feet wide and 12 feet deep. Bottom-chord, of 14 links in each chain of a section 1 by 17 inches. Enc. Brit.

Victoria Bridge at Montreal;[1] while the Saltash Bridge remains the unique example of its type. With further experience, the trussed girder was found to afford better opportunity for economical disposition of materials, for facility in construction and erection and for efficient distribution of stresses among its members. This conclusion was greatly strengthened by results attained in the United States.

Trussed Bridges. The Steel Arch

At an early period, bridge-builders in the United States were skillful in the construction of trussed girders. The favorite type was the lattice-truss. It was simple in design; it required no timbers of unusual dimensions, and could be put together without iron-work and framed by ordinary house-carpenters. By increasing the height of the trusses and by combining arches with them, these lattice-bridges were built of considerable spans, but for railroad purposes, the span rarely exceeded 125 feet.[2] It was impracticable to equalize the stresses between the truss and the arch and, with the increasing loads, the pin-connections were compressed and bent; so that, under the consequent deflection from passing trains, the integrity of the structure was imperilled. Resort was then had to empirical designs of other types.

In 1830, the Howe truss was patented; a panel-truss with vertical rods as tension members and inclined struts or braces as compression members and for counterbracing to resist the wave of deflection from passing trains. In 1840, this type was further improved. At the panel-points, the braces rested against iron angle-blocks, with tubes gained in between the chord-pieces. Through these tubes, the tension-rods passed and were screwed up against wrought-iron gibs on the exterior faces of the chords, thereby furnishing a ready means for restoring any loss of camber. The chords were given greater transverse strength by interposing iron plates to separate the chord-pieces which, at the staggered joints, butted against castings with separating webs provided with ribs that were gained into the continuous pieces at the sides.

In 1844, the Pratt truss was introduced. This truss was a development of queen-post bracing, being composed of two or more upright queen-post systems, combined within one trussed girder as primary, secondary and succeeding structures, supporting each other in transferring stresses from the middle of the girder to its ends. In 1847, Squire Whipple developed the theory of stresses in the members of a truss which was applied in the

[1] Victoria Bridge over St. Lawrence River: 25 spans of 244 feet each, replaced about 1900 by a bridge of modern construction.

[2] The Amoskeag Bridge at Manchester, N. H., was built in 1792, with six spans of 92 feet. The Bellows Falls Bridge over the Connecticut River, 1785–1792, had two spans of 184 feet each. The Colossus Bridge, over the Schuylkill River, was a flat-arched truss of 340 feet. Enc. Brit.

Whipple-Murphy type. This was a queen-post design, somewhat similar to an inverted Pratt truss. In the Warren truss, the struts and ties form alternate equilateral triangles between the chords. A Warren-truss bridge of 390-foot span was built over the Ohio River at Louisville in 1869. An iron bridge of this type was built on the Great Northern Railway in England.[1] Up to 1850, bridges built of white pine were limited to about 150-foot spans; but, as railroads were extended down the Atlantic coast, the yellow-pine forests furnished timber of larger dimensions and capable of resisting greater strains, and the length of spans frequently exceeded this limit. These longer spans were also combined with timber-arches, either attached to the sides of the trusses or cut into the bracing and connected with it by turnbuckles, by which means the strains were adjusted between the trusses and the arches.

The conditions that turned the attention of European engineers to iron-bridge construction were likewise operative in the United States, and, between 1847 and 1857, there was a similar tendency to empirical designs, with the compression members of cast-iron and the tension members of wrought-iron.[2] The Fink bridge was a suspended girder trussed with an inverted king-post system, beginning with a principal post in the middle of the span and the half-spans successively subdivided at intermediate points of support. The Bollman bridge was of a somewhat similar design. But in the end, the panel-truss with pin-connections superseded them both.

As was the case in Great Britain about the same period, there had been little accurate information accumulated as to the variations in the qualities of iron employed in bridge-construction, or of the effects of static stresses and of dynamic shocks upon the accepted types of railroad bridges. Even in 1876, a bridge of the Howe-truss type, built over the Ashtabula River with iron rails for compressive members, collapsed beneath a train, because of faulty connections and the crudity of the design as to details. With the advance in theoretical knowledge, there was an accompanying improvement in structural specifications that was furthered by the entrance into iron-bridge building, as general contractors, of iron-works possessing ample capital. These concerns began to furnish their own designs and specifications, which were prepared by proficient engineers. A novel feature in these specifications was their conformity to assumed conditions and limitations as to the stresses which they could sustain with safety.[3] The first specification for concentrated axle-loads appeared in

[1] Norwich Dyke Bridge, 1851–1853: 250-foot span. Top-chord, hollow castings. Bottom-chord of wrought-iron links, pin-connected.

[2] In 1852 James I. Shipman, Chief Engineer of the Alton & Sangamon Railroad, in Illinois, estimated for iron bridges in its construction, and based his estimates on the cost of an iron bridge built by Squire Whipple across the Canal Basin at Albany. George T. Hammond, "Discussion on Railway Development," Trans. Am. Soc. C. E., Dec., 1911.

[3] A specification for short spans, prepared in 1871, limited the load to two tons

1875. The principal requirement, as to wrought-iron, was that it should have a tensile strength of 66,000 pounds per square inch. Experimental tests afterward reduced this maximum to 52,000 pounds with an elastic limit of 26,000 pounds.

The introduction of rails of Bessemer steel into the United States was followed by the use of that material in the Eads Bridge, over the Mississippi River, at St. Louis; completed in 1874. This bridge has three arched spans of unique design. Each span consists of four double ribs, in which the voussoirs are composed of hexagonal steel bars, clamped together in tubes by wrought-iron couplings.[1] For fifteen years afterward, steel was only used for large members, as for chord-bars. The first large all-steel truss-bridge in the world was built by General William Sooy Smith over the Mississippi River at Glasgow, for the Chicago & Alton Railroad Company. At that time, there was an adverse opinion among engineers as to such use of steel on account of its erratic behavior when subjected to shock and vibration.[2] It was not until 1890 that the use of steel for all bridge-work had become general. Two grades of steel were recognized; one of soft steel with ultimate tensile strength of 54,000 to 62,000 pounds per square inch, and a medium grade of 62,000 to 70,000 pounds. After the substitution of open-hearth or basic steel for Bessemer or acid steel, but one grade was employed, with a tensile strength of 60,000 pounds per square inch.

The adoption of the independent-panel truss for long spans was advanced by the introduction of Bessemer or converted steel as a building material, which made it possible to obtain beams of increased dimensions and of more reliable chemical constitution. The Covington Bridge, built over the Ohio River in 1888, was for some time the longest span of this type.[3] The construction of arched bridges was similarly affected by the use of steel beams in the trussed ribs. The Roebling bridge over the Niagara having become insufficient for the requirements of increasing traffic, it was replaced in 1896–1897 by a steel structure with a center span of 840 feet, the longest span of this type yet constructed.[4] Recently, the

per linear foot, or for 30 tons on driving-wheels within a space of 12 feet, with a loaded train of 20 tons in each 22 feet, proceeding at a speed of 30 miles an hour.

M. L. Byers, Proceedings International Railway Congress, Berne, 1910. Vol. I, pp. 68–80. See the same, also, for other information about bridge-building in the United States.

[1] Eads Bridge: Center-span, 520 feet and two side-spans, each 502 feet. Rise of center-arch, 47½ feet. Side-arches, 46 feet. Upper and lower members of each rib trussed 12 feet apart. Double-track, and above the tracks a roadway, 54 feet wide. Enc. Brit.

[2] Engineering News, March 30, 1916.

[3] Covington Bridge: Center-span, 550 feet. Side-spans, 490 feet, 67 feet wide between centers of trusses, 84 feet deep, carrying two railway tracks, two carriage-ways and two footways. Total weight in three spans, 5000 tons.

[4] Roebling's Niagara River Bridge, 1852–1855: Four wire-cables, 10-inch diameter, in a span of 821 feet, 245 feet above the river. Box girder, 18 feet

Chesapeake & Ohio Northern Railway has been carried over the Ohio River, near Portsmouth, by two riveted-truss spans of 775 feet each, approached on the Kentucky side by a viaduct of 1063 feet, and by one of 823 feet on the Ohio side.

Suspension Bridges

The suspension principle afforded the opportunity for economical construction of long spans on a high grade-line, without the use of false works; but their extreme flexibility made suspension bridges sensitive to deflection caused by moving loads. For this reason, this principle was not adopted in railway construction until about 1850, when a plan was devised for applying stiffening girders to the chains that supported the roadway, with an estimated saving of three-sevenths of the weight of the girders in an ordinary truss-bridge of equal span and carrying an equal live load. Such a railway bridge was built at Vienna, in 1860, of 264-foot span. Two chains, vertically parallel and four feet apart, were stiffened by bracing; the truss then forming an inverted arch from which the floor was suspended. American engineering afforded an early example of the suspension principle in the wire-cable bridge over Niagara River, which was at the time the longest span of a railroad bridge in existence. It was stiffened by trusses, chiefly of timber, which formed a box girder, carrying the railroad track on top and a highway below. Iron girders were substituted for timber in 1880. This design of a suspended box girder was repeated by Roebling in the Brooklyn Bridge, built in 1872.[1]

The catenary curve assumed under the effect of gravitation by a wire-cable becomes more parabolic in form in a chain of pin-connected bars, which is also employed in suspended railway bridges. The trussed suspension bridge is also used in railway work for very long spans. A bridge on this principle has been designed for crossing the Hudson River at New York City, with a span of 3200 feet.[2] But under these conditions, the suspension principle loses much in the way of economy, on account of the loftier piers and more massive anchorages that are required, as well as the increased weight and cost of the suspended trusses. The failure of the Tay Bridge in 1879 exercised an unfavorable influence upon its use for such spans, and led to the abandonment of a similar design for the Forth Bridge.

deep and 25 feet wide. Niagara Falls Bridge, 1896-1897: Center-span, 840 feet. Side-spans, 190 and 210 feet. Weight of center-span, 1629 tons. Two-hinged parabolic arch with trussed ribs, carrying two electric tracks, two roadways and two footways.

[1] For bridges in New York City, see Appendix IV, Table VIII.

[2] A suspension bridge was planned for carrying the Pennsylvania Railroad into New York City with a span between towers of 3000 feet. The towers were to rise 600 feet above water level, and the bridge was to carry sixteen tracks on two decks.

Cantilever Bridges

The impetus given to building long spans by the advance in the metallurgical and mechanical arts, as well as by the better comprehension of the mathematical theory involved in structural stresses, is evidenced in the application of yet another principle in bridge-construction — that of the cantilever. This principle, which is fundamentally the same as the mechanical power applied in the cant-hook, appears in its primitive form in the strengthening of the simple beam by the projection of a support from the abutment, like the bolster or corbel under the roof-rafter. This device added strength to the beam to resist the stresses to which it was subjected, as they increased in magnitude from the middle of the span. In so doing, there was an inversion of the strains of compression and tension from their original relation to the neutral axis in the beam, constituting the contrary curve of flexion which, as in the arch, modifies the thrust from a horizontal to a vertical direction.

The trussed girder, continuous over three spans, is an example of this change of thrust, and the point at which it occurs was practically exhibited in a test of the bridge built over the Boyne, in Ireland, in 1852–1855.[1] By this division of the length of the girder, each of the side-spans slightly exceeded in weight one-half of the central span. Upon the completion of the bridge, a test was made of the accuracy with which the point had been determined at which the strains of compression and of tension were neutralized by their inversion in the curve of contrary flexure. The rivets in the top-chords of the central span were cut at that point, toward one of the intermediate piers, and the shore end of that side-span was lowered an inch with the effect of opening the separated points of the chords by only $\frac{1}{32}$ of an inch. The same process was repeated in the opposite direction with a similar result, thus proving the correctness of the design.

The same principle is also employed in the so-called "hinged-arch," hinged at the points at which the opposing strains of compression and of tension are neutralized; and with economy in the distribution of materials in the structure. Such a bridge was built over the Viaur River in southern France. The ribs are arched Whipple-trusses, with a center-span of 722 feet, and the roadway is 380 feet above the water-level. The shore-ends are two half-spans, each of which was so combined with a half of the center-span as to slightly overbalance it, and each half of the structure was connected by hinges with its supporting pier. The bridge was erected without false-works, by balancing the two half-spans on each side as the work of erection was extended in each direction toward the middle of the central arch and toward the abutments.

From the arms of the cantilever, counterbalancing weights may be

[1] This bridge of trussed girders, $22\frac{1}{2}$ feet deep by 541 feet in length, is supported by two intermediate piers with a center-span of 264 feet.

suspended, and the additional strains resisted by increasing the depth of the compression-member, and by straining truss-rods over a post or tower erected on the pier; or by substituting a trussed girder as the tension-member. In either case, the strains from the suspended load act as they do upon the jib of a crane. By increasing the dimensions of the cantilever, vertically and horizontally, it may cover a half-span to any length commensurate with the factors of safety of the materials of which it is composed.

The cantilever design has been adopted for many railroad bridges of long span on a high grade-line. Among these are the Niagara Bridge built in 1883, and the Poughkeepsie Bridge over the Hudson River.[1] Independent truss-spans may be erected without falseworks by temporarily connecting them over the piers as cantilevers and then building them outward until they meet in the middle of the span. Two cantilevers may be opposed to each other with an intervening space covered by a trussed girder span suspended from their opposite arms, forming virtually a continuous girder, hinged at the points of contrary flexure. In many places, this is the most economical plan for a bridge with a long span and on a high grade-line; as the cantilevers can be built out from each pier without expensive falseworks or obstruction to navigation. The suspended truss may be assembled on the cantilevers and rolled into place or be raised into place from the water-level. The Forth Bridge was designed on this principle. The shore-arms of the side-cantilevers are loaded to balance half of the weight borne by the opposing arms and two hundred tons besides.[2]

The Queensboro Bridge, over East River in New York City, has a span of 1182 feet of cantilever type with suspended pin-connected trusses. The bridge over the St. Lawrence River at Quebec, which collapsed on August 29, 1907, during erection, was the longest span yet attempted of this type. This bridge had been designed by an engineer who was recognized as an authority on the subject, and it had been constructed by one of the leading bridge-contractors in the United States. After an investigation by a commission of experts, another design of the same type was accepted. On September 11, 1916, the suspended truss fell into the river as it was being

[1] Niagara Cantilever Bridge: Double track, 910 feet in length. Center-span, 495 feet; subsequently strengthened.

Poughkeepsie Bridge, 1886–1887: 200 feet above water-level. Five river-spans of 547 feet each and three shore-spans of 208 feet each. The trusses over the second and fourth piers are extended as cantilevers over the adjoining spans. The shore-piers carry cantilevers projecting one way over the river-openings and the other way over a shore-span, where they are secured to anchorages.

[2] Forth Bridge, 1882–1889, opened 1891: Total length, 5330 feet. Two center-spans, each 1710 feet. Suspended trusses, 350 feet long. Cantilever towers, 260 feet high. Piers, 145 feet high. Six cantilevers, 680 feet each. Double-tracks carried on an internal viaduct of lattice girders. Total weight, 38,000 tons, exclusive of approaches.

lifted by hydraulic jacks from floats below into its position between the cantilever arms, apparently from a failure in some part of the lifting appliances. The following year a new suspended truss was successfully lifted to place, completing the bridge.[1]

A fixed span may be extended over the supporting piers in cantilever-arms. There is an example of this design in the Harahan Bridge over the Mississippi River at Memphis. To one of these arms is suspended a truss which is supported at the other end on a pier.[2]

DRAW-BRIDGES

Where a bridge crosses a navigable stream on a low grade-line, an opening must be provided sufficient for the passage of watercraft. This opening is spanned by a draw-bridge, which may be operated vertically as a lift-bridge, or horizontally as a swing or turning bridge. The early highway draws were lift-bridges of the bascule type. This contrivance was borrowed from the bridges over the moats of feudal fortresses, which were raised by levers resting on the entrance walls and counterweighted within. Modern examples of this type have usually two leaves, meeting when closed in the middle of the opening. The girders revolve on a horizontal axis near the face of each pier, with the counterweighted arms describing an arc in chambers within the piers. The Tower Bridge over the Thames in London is of this type.[3]

Railroad draw-bridges are usually of the swing or horizontally turning

[1] Original Quebec Bridge: Length between abutments, 3240 feet. Channel span, 1800 feet. Suspended truss, 675 feet. Shore cantilever-arms, each 562½ feet. Total weight of metal, 32,000 tons. Designed to carry two steam-railroad tracks, with a highway and an electric railway on each side; all between the main trusses.

New Quebec Bridge: Two piers, each supporting a cantilever with a river-arm of 580 feet, carrying a suspended truss of 640 feet, making a channel-span of 1800 feet. Shore-arms, each 515 feet, outer ends resting on piers connected with one shore by a truss of 140-foot span and, with the other, by a truss of 269 feet. Total length, 3239 feet. Width, 88 feet between trusses. Double-track, with two sidewalks. Contracted to be completed by December 31, 1915, for $8,560,000. Opened for traffic, December 4, 1917.

[2] Harahan Bridge, opened July 15, 1916: Total length, 2549 feet, connected with a steel viaduct, 2363 feet in length. Double-track, 14 feet between centers, with highways 14 feet wide on cantilever-brackets outside of the trusses. Clearance inside, 8 feet on each side and 24 feet above base of rail. Channel-span of 621 feet, extended over piers in cantilever-arms of 186 feet each. Each arm supports a suspended truss of 418 feet. One of these is supported at the other end by a pier which also supports a deck-span of 347 feet. The other suspended truss is also suspended to a cantilever with arms of 186 feet, making a span of 790 feet; the other cantilever arm being anchored. As so constructed, there are successively a deck-span of 347 feet, and three through spans of 607 feet, 621 feet and 790 feet.

[3] Tower Bridge: 200 feet clear opening. Double-bascule, rotating through an angle of 82 degrees, on steel shafts 21 inches in diameter and 48 feet long. Lifted in one minute by hydraulic power. Short-arm girder, 62 feet 6 inches in length, carrying 365 tons of counterweights.

type. Over narrow openings, as over canals, they may be operated from one of the piers, as was the case with the early "jack-knife" draws. In this style of draw-bridge, each rail is laid without ties on a separate stringer or girder hinged to the pier. The outer ends of the girders, while swinging, are suspended by links from a gallows-frame on the pier and are connected by a parallel-ruler hinge which holds them at gauge when the draw is closed. The suspension-chains or rods are attached to the ends of a cross-arm, which is pivoted at the middle of the parallel-ruler hinge and are lifted by levers operated on the pier. The draw is opened by a rope attached to the outer end of the draw which is manipulated from the end of the pier-guard. In later designs, the draw is opened and closed by winch-operated gear, meshing in an arc fixed to one of the girders. When the draw is open, the girders fold close together at an angle of about 80 degrees to the line of road.

The usual type of railroad draw-bridges is the pivot-draw, resting upon a turntable supported by a pier midway in the opening, and leaving a passage on each side. A trussed girder supported in the middle may be so balanced that the strains on each side can be equalized. This is the principle of the cantilever as operative in the pivoted-turning draw-bridge, of which the bridge over St. Louis River at Duluth is a notable example.[1] The weight of such a draw-bridge, including the turning apparatus, is about the same as that of a fixed span of equal length carrying the same load.

The first four-track draw-span in America was built about 1897 over the Harlem River, for the New York Central & Hudson River Railroad Company. It has three trusses, 389 feet between end-pins and 26 feet apart, carrying the four tracks on a ballasted floor and weighing 2500 tons. The draw-bridge over Conneaut Harbor, Ohio, on the Bessemer & Lake Erie Railroad, carries four tracks with only two main trusses; two tracks are between the trusses and one each on an overhang. The floor-system is supported by deep overhead transverse trusses with cantilever extension to the outer ends of the overhangs. There is no center-tower; the stresses in each truss are brought to one point on the center pier. The entire dead weight of 1400 tons is carried, when the bridge is open, by a compound box girder on a pintle-bearing without the support of a turntable. This construction was made necessary by the limited height of the tracks above high-water level.[2] A reliable locking-apparatus, connected electrically

[1] Duluth Bridge: Opening of 500 feet, spanned by a pivot-draw, 58 feet wide, carrying double-tracks between trusses and carrying on each side, on cantilevers, an electric street-railroad and a footway. Opened in two minutes by electric motors. Ends lifted four inches by electric motors, which also release the latches and raise the rails.

[2] Conneaut Draw-bridge, built in 1912, is of the Warren triangular-truss type, 235 feet long, 32 feet 7 inches between centers of trusses and 67 feet in width over all. Height from base of rail to masonry, 5 feet 8 inches, and floor-system 3 feet in depth. Center-bearing of phosphate bronze, 34 inches in diameter.

with the track-signals, is indispensable to the uninterrupted passage of trains over a draw-bridge. Otherwise, all trains should be brought to a full stop at least 600 feet from the opening.

Recent Examples of Bridge Construction

The effects of increase in traffic and of the corresponding increase in the tractive power of locomotives upon the requirements in bridge-construction, are shown in the history of the Pittsburgh & Lake Erie Railroad's bridge over the Ohio River at Beaver, Pa. The original bridge, built in 1878, was renewed in 1890 upon the single-track masonry with a structure thought sufficient for many years to come. But, by 1897, the increased tractive power of the locomotives on the line had permitted an increase in train-tonnage of from 1600 to 2500 tons. About 1902, there was a further increase in tractive power with a corresponding increase in train-tonnage to 3500 tons, which was subsequently increased to 4200 tons. With these changes, there was laid a double-track approach to the bridge; then a single-track gauntlet across it, then four tracks to a point near the bridge, and, finally, it became necessary to reconstruct the bridge itself.

The piers were not large enough for double-track, and it was desirable to relieve navigation by removing one of the channel-piers. For these reasons, in 1906, it was decided to build another bridge on a new location, 90 feet in the clear above low water, with a cantilever-span of 769 feet between centers of piers. The location of this span compelled one arm of the south cantilever to be entirely over land, with an approach-span at the north end of the other cantilever. The bridge was designed for two gauntlets. The tracks in each gauntlet have their adjacent rails a foot apart between centers. Both freight-tracks lie toward the center-line of the bridge, 13 feet on centers, and the passenger tracks are 15 feet on centers. The side-clearance is 7½ feet from centers of passenger tracks to the trusses and 7 feet to the skid-girders; and the overhead clearance is 21½ feet above the rails.

The length of the anchor-arms is 320 feet, of the cantilever-arms 252 feet, of the suspended truss 285 feet, and of the approach-span 370 feet. The trusses are 34½ feet between centers and 30 feet in the clear. The river-clearance and grade-conditions made it necessary to have a shallow floor-system with only 6 feet between the clearance-line and the top of the rail. A special feature of this construction is the protection against derailment. There are nine lines of stringers, four under each gauntlet and one half-way between. The ties are of white oak, chemically treated,

Maximum load on overhangs is 6100 pounds per lineal foot of track. The bridge is turned by two pairs of pinions, connected by equalizers, on a rack with pitch diameter of 41 feet. "A Four-track, Center-bearing Railroad Draw-Span." L. H. Shoemaker, Trans. Am. Soc. C. E., December, 1912.

7 by 9 inches, 12 feet long, placed on edge and sized to 8¼ inches. They are three inches apart, with three lines of spacing-blocks on each half of the floor. The surface of the ties is 1½ inches above the tops of the floor-beams and ½-inch away from them, in order to allow cinders to be blown off the floor-beams by passing trains. Wooden guards could not be used on account of the steel-car construction with drop-doors; so, beside the gauntlet tracks, there are four inner guard-rails, making twelve lines of 100-pound rails. The rails are 33 feet long, supported on double-shoulder tie-plates secured to the ties by screw-spikes. The splices allow ⅜-inch expansion at each joint.

Skid-girders prevent the car-bodies from striking the trusses in case of derailment. There are two girders for each truss, respectively four and six feet above the ties, with chords on each side of the truss made up of 6″ × 6″ angles and web-plates — 12½″ × ½″ plates on the inside and 10¼″ × ½″ on the outside. These chords are 5 feet 4½ inches apart and are connected by 3½″ × 3½″ angles. The track-faces are smooth, with countersunk riveting and are provided with expansion-joints.

The floor-system is designed to carry a train on each track, weighing 6000 pounds per linear foot, each preceded by two locomotives weighing 426,000 pounds each. The dead load averages about nine tons per linear foot. The wind-loads were computed at 300 pounds pressure per linear foot on a train and 30 pounds per square foot on exposed surfaces of trusses and floors; 10 pounds per square foot being treated as uniformly distributed, and 20 pounds as a moving load, wherever it produced the maximum effect on the members.

The total weight of materials is 6184 tons. The bridge was tested with eight locomotives and twenty loaded cars in two trains, one for each track, weighing on each track 2,842,200 pounds, placed side by side; the trains being entirely in the cantilever arm and the suspended truss. There was a maximum deflection of 0.467 inch on the cantilever and suspended truss and of 0.069 inch on the anchor-span. The bridge was completed in May, 1910.[1]

A bridge recently constructed over the Ohio River between Metropolis, Ill., and Paducah, Ky., has a channel-span of 723 feet between centers of piers, which is probably the longest single span in the world by fifty feet.[2]

[1] "The Pittsburgh & Lake Erie Railroad Cantilever Bridge over the Ohio River at Beaver, Pa." A. R. Raymer, Trans. Am. Soc. C. E., September, 1911.

[2] Bridge over Ohio River at Metropolis, Illinois: Double-track. Channel-span on south side of the river of 723 feet, four spans of 555 feet each and a span of 304 feet on the north side. South of channel-span, a deck-truss of 250 feet. A viaduct-approach on each end, composed of tower-spans of 30 feet, with intervening clear spans of 65 to 90 feet. Total length, 5442 feet. Pin-connected trusses. Track 113 feet above low-water mark and 52 feet clear head-room above high water. Railway Age Gazette, July 23, 1915.

General Principles of Bridge Design

The preparation of a bridge-plan involves primarily a consideration of the weight and speed of the normal moving load or live load. The axle-loading and spacing of the heaviest locomotive which would probably be operated upon the line in question are used in the computation of stresses in the various members.[1] The height of the grade-line above the natural surface of the opening to be crossed, the width and depth of the water beneath and the character of the underlying soil, are important factors in determining the division of the superstructure into spans, within the physical limits of safety in the materials to be used, and also in deciding upon the type of superstructure. As the span increases, the effect of the live load becomes more negligible, until the point is reached at which the dead weight of the superstructure itself restricts any further length of span. The superstructure must be designed with reference to wind-pressure, and the effect upon the floor-system of the wave of deflection and the shock from impact of passing trains, and must provide for expansion in all its parts under changes of temperature. The length of span is proportional to the depth of the truss, which may vary from one-eighth to one-twelfth of the span.[2]

Because of improvements in the state of the metallurgical arts, in the control of the chemical elements, and of the molecular constitution of iron and its heat treatment, as also in the tools and appliances for fitting, handling and erecting heavy bridge-members, structures once impracticable are now designed with closer approach to theoretical requirements; there is also a general agreement about the chemical and physical qualities of the materials required, and as to the tests for their determination. Each member has a definite function and is adjusted to a calculated stress. It has therefore become possible to reduce the empirical factors of safety in bridge-construction with material advantage as to cost and with greater economical efficiency.

American practice is characterized by types easy of construction and

[1] The live load in early practice was estimated at one ton per foot of line, but the weight of a locomotive of the Consolidation type corresponds to a load of 2½ tons per linear foot. The total weight of a bridge when loaded was at first limited to five tons per square inch of section of truss-members. This limit is now raised for steel structures to nine tons per square inch; the live load being estimated at twice its actual weight.

[2] For parallel steel chords, one-tenth of the span, the theoretical limit is 1070 feet.

For parabolic or bowstring chords, one-eighth of span, 1280 feet.

For flexible suspension bridges of linked bars, with depth one-twentieth of span, 2800 feet.

For stiffened wire suspension bridges, depth one-tenth of span, 2700 to 3600 feet, and for one-eighth of span, 3250 to 4250 feet, according to the assumed factor of safety.

In practice, the limits as to length of span are less than here given.

erection. There is a preference for trusses of great depth, with long members of rather small cross-section, giving an appearance of lightness, and for the use of eye-bars for tensile members. For spans up to fifty feet, riveted plate-girders are favored and riveted trusses up to seventy-feet span.[1] For longer spans, pin-connected trusses are more generally preferred here than by European engineers. It is customary to prepare a general plan, designed upon one of the accepted types, with specifications, strain-sheets and drawings sufficiently in detail to secure to bidders an understanding of the requirements. Much of the structural material is designed of standard dimensions and is carried in stock by the manufacturers. Wide discretion in the details of construction and manner of erection is given to the contractors, who are in general provided with competent engineers and experienced workmen, and are well equipped with tools and appliances suitable for their work. Under these circumstances, economy, accuracy and expedition in bridge-construction has been greatly furthered. European engineers usually individualize in bridge-planning, even to details of manufacture. They favor riveted construction and shallower depth of truss, involving an increase in the sections of various members and a general increase in the weight of a bridge. The two schools are, however, over-lapping. Eye-bars are becoming more common in European design, and riveted bridgework is increasing in America.

With increasing axle-loads and higher speeds, the effect of impact from dynamic shocks has assumed greater importance. In earlier practice, impact-effect was rather a matter of empiric assumption. Recent experimental tests have tended to enlarge our knowledge in this respect. It is now considered that the more serious effect of impact is principally due to imperfect counterbalancing of the driving-wheels. The maximum effect appears to be about 50 per cent. in spans not exceeding fifty feet, decreasing with the length of span until, for spans over a hundred feet, the maximum effect may be assumed at 15 per cent. It is especially cumulative where the rate of revolution of the driving-wheels synchronizes with the normal rate of vibration in the structure, but it is negligible at speeds under fifteen miles an hour.[2]

The increase in axle-loads and in train-loads, as well as in speed, has encroached upon the factors of safety in many of the earlier bridges to a point at which it becomes necessary to replace them, unless they can be strengthened where they are critically weak. To renovate such bridges

[1] The longest single-span girder in use is on the New York, Chicago & St. Louis Railroad; 130 feet by 9 feet 8½ inches in depth. To shield the floor against blast-action and smoke-gases from locomotives passing beneath it, the under side of the floor is protected by a cement-gun coating and by cast-iron blast-plates, three feet wide, hung directly over the center-lines of the tracks. Engineering News, December 9, 1915.

[2] M. L. Byers, Proceedings International Railway Congress, Berne, 1910. Vol. I, Sec. II, p. 72.

with assurance of safety, required a knowledge of their weak points which could only be obtained by computation of the additional stresses, and by experimental tests as to the points at which these stresses had gained upon the original factors of safety. There was further required an approximately accurate knowledge of each bridge in detail, from a careful examination of the condition of its several members. Where the stresses are concentrated at pin-connections, the normal factor of safety may have been diminished by wear to an extent difficult of detection from casual observation. The riveted truss, in which the stress is distributed among the rivets, has fared better under increased loads. But in cases of short spans, it has been found preferable to replace these with riveted plate-girders. The floor-system usually exhibits the first symptoms of distress from overloading. Other serious defects are made apparent by loose rivets, by streaks of rust and by cracked paint and generally by excessive deflection and vibration under passing trains. There is ordinarily an ignorance of the history of the earlier bridges, as to the qualities of the materials of construction and as to the manner of erection that overshadows with so much doubt any scheme for strengthening them, as to render it advisable to replace such bridges with structures of known conformity with the changed requirements.

Even with bridges of more recent construction and of a magnitude requiring the best knowledge attainable as to their design and materials, the demands as to speed and loading have so far exceeded what has been recognized as normal, as to call for extensive alterations to meet the changed conditions. The bridges over the East River in New York City are cases in point. Within twenty-six years after the opening of the Brooklyn Bridge, it was estimated that an expenditure of not less than $15,000,000 would be required for their partial reconstruction. Besides strengthening the details of the Brooklyn Bridge, the number of Rapid Transit trains permitted upon it at the same time has been materially reduced, and another deck is to be added to the middle span. The Williamsburg Bridge, opened in 1903, has been strengthened in the main trusses, and supporting piers placed under each land-span and each end of the main span. The end-pins, 10 inches in diameter, have been replaced by others, 13 inches in diameter. As to the Queensboro Bridge, opened in 1909, a board of engineers reported in 1908, that all Elevated Railroad and Subway trains should be excluded, the live load reduced one-half on the roadway and one-third on the sidewalks, and the dead weight reduced by 2000 pounds per linear foot. In 1914, it was proposed to reconstruct the floor-plan by placing the trolley-tracks outside of the main trusses on the lower deck, and the sidewalks outside on the upper deck; one-half of the width between the main trusses on the lower deck to be utilized for Subway trains, and half of the upper deck for Elevated Railroad trains. On the Manhattan Bridge, completed in 1910, it has only been found necessary to shift the anchorages about three inches to provide for the wider car-bodies of the Subway trains.

Bridge Foundations. The Pneumatic Process

Progressive improvement in the arts connected with bridge-building has been as conspicuous in foundation-work as in superstructure. The empirical experience of the well-digger in sinking kerbs through loose soil or water-bearing strata, had resulted in such skill in the use of sheet-piling, coffer-dams and caissons that, for a long time, railway engineering developed no novelty of importance in foundation-work. The steam pile-driver had supplanted manual labor at the winch-handles; light-houses and piers were founded on iron piles screwed into the sea-sands or sunk by water-jets, but engineering work of this character continued on the same general lines until the employment of compressed air in subaqueous construction.

Diving-bells had been much used for subaqueous work until the introduction of compressed air for this purpose. It is stated that in 1778 Smeaton sank the foundations for a bridge at Hexham, in Northumberland, by the use of compressed air. In 1830, Sir Alexander Cochrane (afterward Lord Dundonald) patented the use of compressed air in working in water-bearing strata for bridge-foundations and pier-construction, though it seems not to have been practically applied. In 1849, Treger used pneumatic caissons for driving through river-sand. In 1851, Sir Charles Fox applied an expedient known as "Potts' Pneumatic Process" in the construction of a bridge over the Medway, at Rochester, in connection with the first iron caissons used for subaqueous foundations.

Potts' process was introduced into the United States about 1852, and was first employed in founding the piers of a bridge over the Great Peedee River in South Carolina during the construction of the Wilmington & Manchester Railroad, now a part of the Atlantic Coast Line. The river-bed, to a considerable depth, consisted of coarse sand, easily scoured by freshets; conditions very unfavorable for founding masonry-piers upon a timber-platform, either by a coffer-dam or by a caisson. Under these circumstances, the pneumatic process was adopted by the Chief Engineer, L. J. Fleming.

The piers were composed of cast-iron columns in pairs, the draw-pier being a group of five. These columns were in sections of nine feet in length and six feet in diameter, bolted together by internal flanges in lengths sufficient for the top of the column to be above water when its bottom rested on the river-bed, supported by a surrounding stage of piling. A cast-iron air-lock was attached to the upper end of the column and connected with a steam air-compressor on the staging. The sand from the interior was sent up through the air-lock in canvas-bags and, as it was excavated beneath the chamfered edges of the bottom-section, the column descended by its own weight, being kept plumb by guide-piling. When a depth was reached below the scouring action of freshets, the interior was made watertight with a layer of cement and then it was filled up in the open with concrete. This process was repeated at the bridge over the Santee River, on the Northeastern Railroad, and at the Savannah River Bridge on the Charleston & Savannah Railroad; the latter being left incomplete at the beginning of the Civil War. Both of these roads have since been merged with the Atlantic Coast Line.

The pneumatic process, as thus practiced, had objectionable features. The air-lock had to be hoisted off to attach each additional section, and the passage of men and of materials through it was slow, and inconvenienced by the circumscribed space. The air-content of the whole column had to be maintained at a pressure just sufficient to counterbalance the varying depth of the river. If the pressure were insufficient, the water rose inside; if it were in excess, the air blew out underneath. As it rose in bubbles along the surface of the column, there was a consequent reduction of skin-friction against the sand thus set in motion, which took place unequally and tended to throw the column out of plumb. Occasionally its descent was arrested by excessive friction, and it became necessary to order the men out and to overload the column with rails to force it down. Snags buried deep in the river-bed caused serious delay in cutting them free of the descending column. If they protruded above the surface of the river-bed, they were liable to shoot out when freed, followed by a blow-out that imperiled the men inside.

These difficulties were obviated to a great extent, and the value of the pneumatic process largely augmented, by transferring the air-lock from the top to the bottom of the pier, thus converting it into a caisson of any desired area, connected with the outer air by open shafts. The caisson served as a foundation for a masonry pier, whose increasing weight maintained its descent as the excavation progressed, and the number and dimensions of the shaft could be suited to the rapid handling of materials both ways and at the same time. After a sufficient depth had been reached, the caisson could be filled in and remain as a foundation. Electric illumination was substituted for the oil-lantern and the telephone replaced signalling by hammer-blows upon the shell of the column.[1] The pneumatic caisson underwent a far more important development in its application to subaqueous tunnel-work in connection with the excavating shield.

Cement and Concrete. Reinforcement

As the advance in the metallurgical arts, following upon Bessemer's discoveries, inaugurated a new era in iron-bridge building, so the contem-

[1] The foundations for the Eads Bridge at St. Louis, completed in 1874, were sunk by the compressed-air process to rock-bottom, 136 feet below high water. The piers supporting the Forth Bridge, 1882–1889, were sunk forty feet beneath the river-bed upon pneumatic caissons, 70 feet in diameter.

porary development in concrete work gave a similar impetus to masonry-construction. From the days of the Later Republic, concrete had been generally used in Rome for building important structures, with the wall-openings formed in brick; of which the Basilica of Constantine, or rather of Maxentius, is a notable example. The lime burnt from the materials in that vicinity proved particularly suitable for work under water, but, as these natural earths were not widely distributed, hydraulic lime was not generally used. In 1791, a method was introduced for preparing it artificially from marl; the product being known as Roman cement. Regions abundant in marl profited greatly by this discovery until it was found that the elementary materials, lime, silicates and clay, when mixed in suitable proportions, would produce hydraulic lime superior to Roman cement, known in the United States as Rosendale cement. The manufacture of this artificial or "Portland" cement has now become a leading industry in every country in which its component elements can be obtained, with a greatly increasing substitution of concrete for stone and brick work. In the United States, the production has increased as follows: 1880, 42,000 barrels; 1890, 335,000 barrels; 1900, 8,482,000 barrels; 1910, 68,205,000 barrels.[1]

Concrete is usually composed of about one part of cement to two of clean sand and three to five of broken stone or bricks, or gravel. It was formerly used only as rubble or molded in blocks, known as béton in France, where blocks weighing 350 tons each have entered into the construction of break-waters and other marine works. In 1868, Morier, a French gardener, invented a method of making water-basins from cement strengthened with wire-netting. From this invention there has been a remarkable development of the art of masonry in the use of concrete molded in forms or frames in connection with iron wire or rods, so combined that their respective resistance to stresses of compression or of tension are advantageously utilized. By 1880, reinforced concrete had become a material of recognized value in railway engineering. Because of its ready adaptability in many forms for walls, floors, beams or columns; its fire-resisting qualities; its cheapness as compared with masonry of brick or stone, and the expedition with which concrete work can be carried on to completion, it is extensively used in superstructures, piers and foundations of important bridges, as well as in architectural work.

[1] Portland cement is a compound of calcium, silica and alumina, being a mixture of 1.7 parts, by weight, of lime to 1 part of silicious matter containing soluble silicates with an additional component of alumina and iron, burnt to incipient fusion. The resulting clinker contains from 60 to 64 per cent. of lime, 19 to 25 per cent. of silica and 5 to 9 per cent. of alumina. After it has been ground, there is added about 3 per cent. of gypsum or calcium sulphate, to regulate its setting time. Portland cement attains its maximum strength after hardening from six to twelve months. George P. Diekmann. Journal Am. Soc. Mech. Eng., May, 1916. G. A. Rankin. *Ibid.*, Sept. 1915.

Recent and conspicuous examples of structures in reinforced concrete are the Hudson Memorial Bridge over Harlem River and the viaducts on the extension of the Florida East Coast Railway; a project which would have been impracticable with any other material.[1] Cement containing a considerable proportion of gypsum should not be used in concrete work exposed to sea-water, as its consequent reaction tends to its gradual disintegration. The usefulness of reinforced concrete will be much enhanced if the suggested photographic examination with Roentgen rays of the steel reinforcement can be made practically available.

TUNNELING. ANCIENT AND MODERN EXAMPLES

Where the established grade-line must penetrate the natural surface beyond the limits of economical excavation by an open cutting, engineering provides the efficient means for prosecuting the work by tunneling. Tunneling is an ancient art, originating in quarrying and mining operations. In Ancient Egypt, subterranean tombs were excavated in solid rock, and tunneling was applied to the drainage of inundated lands. Lake Copias was drained by tunneling 150 feet beneath the adjacent surface. The art of underground excavation was further developed in connection with the water-supply of cities. On the island of Samos, an aqueduct built about 625 B.C., included a tunnel 4200 feet long of a section eight feet square. In the construction of navigable canals in Europe, further experience was gained in subterranean excavation and, with the general advance in engineering, tunnel-work of considerable magnitude was undertaken, such as the Steinedge Tunnel, three miles in length, on the Huddersfield Canal in Yorkshire. Resort was also had to tunnel-work in the construction of important highways through mountainous districts, of which the Simplon Road is a notable example.

Accuracy of alignment is imperative in driving tunnels. Before the invention of telescopes, the alignment was established by the water-level in connection with an instrument for measuring angles of deflection. The general direction of a tunnel of considerable length could only be preserved by prosecuting the work from intermediate shafts at frequent intervals; and the penetration of the tunnel beneath the natural surface depended on the depth to which it was practicable to sink these working-shafts. In 82 A.D., Lake Fucino in Italy was drained by a tunnel 3½ miles long and 10 feet by 6 feet in section, aligned by forty shafts, some of them 400 feet in depth. The skill now acquired in the adjustment of the instruments used in alignment, is exemplified in the spiral tunnels on the St. Gotthard Rail-

[1] On the electric railway recently constructed between Chur and Arosa in Switzerland, there is a bridge of reinforced concrete with a span of 315 feet in the clear and a rise of 140 feet, intended for a normal load of 44-ton motors and 33-ton trailers. The fan-shaped centering rested on three reinforced concrete towers. Engineering News, March 9, 1914.

way and also in the Simplon Tunnel, where it was impracticable to test the instrumental work during construction, from the absence of shafts throughout its length of twelve miles.[1]

TUNNELING FOR RAILWAYS

The introduction of railways gave a further impetus to tunnel-construction. The necessity for keeping the ruling-gradient within the practicable limits of the adhesive weight of the locomotive, often left no alternative to tunneling, if the volume of traffic justified the additional expense. To meet such conditions, railways were projected to cross mountain ranges at great elevations, with the increasing confidence due to progressive experience and the application of engineering genius and skill to devising improvements in methods and appliances. The Alpine region of Central Europe affords so many examples of this character as to warrant some detailed account of the latest tunnel-work in that region.[2]

The penetration of mountain-ranges by railway tunnels calls for thorough preliminary investigation, with especial attention to geological conditions. These can be predetermined with approximate accuracy where the stratification is at a considerable dip and at right angles to the projected line. Such predetermination increases in uncertainty as the subtended angle decreases between that line and the strike of the stratification, and with its lesser dip. It becomes virtually impracticable where the stratification is contorted or folded. It is also important to determine whether the rock will be found solid, broken or decomposed. In lime-stone regions, the conditions to be expected are variable ground, with frequently great pressure, strong inflow of water and occasionally fire-damp. From present experience, the zone of rock-pressure does not increase with the depth below the surface, and has not been especially dangerous in long tunnels. In a part of the Simplon Tunnel where there was great pressure for a distance of 46 yards, it was due to an unstable mass, not more than from 600 to 1000 feet in depth, and did not correspond to the pressure which should have been produced at 4000 feet below the surface.

The movement of sections of the superincumbent mass, the percolation of water, excessive temperature and foul air, often expose the working forces to imminent peril and greatly delay the prosecution of the work, with material increase in its cost. At the Tenda Tunnel, in Italy, a fault

[1] In the construction of the tunnel under the Mersey, between Liverpool and Birkenhead, 1881–1886, shafts were sunk on each shore for a drainage-driftway, 180 feet below quay-level and outside of the tunnel-section. From these shafts, offsets were made to the center line of the tunnel, which was then projected from a base line of twelve feet, upon a rising gradient of 2 feet in 1000 to the middle of the river, with a total length of 1350 yards. The main tunnel, driven down-hill in advance of the drift-way into which it was drained, was connected with a total error of 2½ inches.

[2] For elevations attained in railway location, see Appendix IV, Table I.

of 47 yards led to the abandonment of the work by the contractor. After great delay, the passage was effected at a cost of about $60,000. At the Loetschberg Tunnel on the line from Spiess to Brieg, in Switzerland, the geologists predicted solid rock under the bed of a mountain-stream which was 558 feet above the tunnel-section and, as supposed, with 328 feet of solid rock overhead. Yet, at a point nearly two miles from the tunnel-mouth, the stream burst through a fissure, filled the tunnel with sand and gravel to within a thousand feet of the entrance and buried twenty-five men. The line was in consequence diverted and lengthened 805 yards. In the Karawanen Tunnel, on the new line from Vienna to Trieste, three miles in length and completed in 1906, the rock-pressure set a section in motion extending for 1¼ miles. Nearly two years' delay was thereby occasioned.

In double-track tunnels, these difficulties are more readily surmounted, and the lengthening hauls of materials and supplies within the tunnel are less troublesome and expensive. For these reasons, even where the second track is not demanded by present traffic considerations, in the end the double-track tunnel may be found to have been built at less cost than for a single track. The Simplon Tunnel was planned for a single track with passing places. As the work progressed, unexpected conditions as to temperature called for fresh air in volume requiring a conduit of dimensions for which there was not sufficient space in the working-section. A ventilation-heading was therefore driven beside the tunnel, to be utilized as the bottom-heading, whenever a second tunnel should be required.[1] Two tunnels so close together may cause the masonry to give way from excessive pressure, producing serious obstruction in both tunnels. For these reasons, the plan of the Loetschberg Tunnel was changed to double-track at an increase in the estimated cost of $1,250,000.[2]

The inside dimensions of single-track tunnels in Europe seem sufficient to insure safety in operation, but it is deemed advisable in future construction of double-track tunnels somewhat to increase the width, as the use of larger and longer rolling-stock is gradually decreasing the clearance between the loading gauge and the tunnel walls. In curves, the clearance may be slightly increased by shifting the tracks more to the inner side.[3]

[1] The enlargement of this heading for a second track was commenced on the north end December 20, 1912, and on the south end March 30, 1913. The tunnel was completed May 29, 1914, at a cost of $5,307,500; the estimated cost having been $7,000,000. The cost of the double tunnel, exclusive of ballast, truck and electric installation, was $16,598,000, or $255.25 per linear foot.

[2] In France, single-track tunnels of standard gauge rarely exceed 1¼ miles in length, though, on electrically operated lines, there are such tunnels from 3 to 4¾ miles in length. In Italy, there are steam-operated single-track tunnels from 1¾ to 3¼ miles in length, and a single-track tunnel constructed in Switzerland, in 1910, is 5¼ miles long.

[3] The usual cross-section for double-track tunnels in France is from 26 feet 3 inches to 26 feet 11 inches at imposts, 24 feet 7 inches at rail level and 19 feet 8 inches above rails; though some recent tunnels are 28 feet 6½ inches in width. Recent tunnels in Austria are 26 feet 11 inches at imposts and 21 feet above

Methods of Tunnel Construction

There are two methods for carrying on tunnel-work, known as top-heading and bottom-heading, which are adapted by modifications to meet varying conditions. In the Alpine tunnels and in long tunnels elsewhere in Europe, except in France, the bottom-heading has been found preferable. With top-heading, the time for completing the tunnel after the headings have met has been longer, and it is more difficult to maintain the working-tracks and the temporary drainage. The piping for ventilation and air-supply has to be shifted oftener, and taking out the excavated material at the level of the imposts interferes with the masonry-work. With bottom-heading, the temporary track may usually be kept close up to the working-face and is not subsequently disturbed. The drainage gives less trouble, as a drainage ditch or even a completed culvert may also follow closely upon the advance in the heading. In some of the Alpine tunnels, instead of top-heading, the bottom-heading has been extended upward in successive stages with inclined blast-holes. The rock thus offers less resistance, and difficulties in ventilating a top-heading are avoided.[1] Bottom-heading is undoubtedly preferable when the work is not less than three miles from the entrance, especially when there is reason to expect rock-movement or a considerable inflow of water.

A third method has been introduced in tunnel-work, known as underheading, to which attention was directed in Switzerland, in 1897. By this method, a heading is first driven upon the center line, and beneath the tunnel-section, for an independent drainage-tunnel; it is about nine feet wide and seven feet deep, as to the interior dimensions of its masonry-lining. This underheading is kept in advance, followed by the usual bottom-heading. As the underheading receives its lining, air is blown through it into the tunnel proper, and the working-faces above are ventilated by a temporary installation, where compressed air is not used for drilling. In solid rock, the lining may be kept at a distance of 600 to 700 yards behind the working-face of the underheading. This distance allows the use of a larger number of trucks to hold the excavated material before a train is shifted out, and with corresponding expedition in the progress of the work. The underheading-track is used for receiving material from the bottom-heading as well, with relief to the track in the main tunnel and with better opportunity for adapting its timbering to pressure from rock-movement. In case of an inburst of water, it is carried off through the underheading, without interruption to the work on the main faces. Where there is a movement of the rock, the lining in the underheading is carried as closely

rails. Single-track tunnels in France are 16 feet 5 inches at imposts; in Austria, 18 feet; in Italy, on older lines 15 feet 1 inch at imposts and 16 feet 5 inches headway, and on newer lines 18 feet at imposts with 19 feet headway.

[1] In the Albula Tunnel, there was a saving of from $18 to $27 per linear yard by this method, as the blasting was easier and the ventilation was better.

as possible to the working-face, and access is afforded to the bottom-heading through successive openings in this lining as the bottom-heading is extended, and with greater facility for timbering. The completed underheading serves not only for drainage but also as a conduit for permanent ventilation and for the cables required for telegraphs, telephones, electric lighting and signaling apparatus, as well as for electric traction. It has been proposed to lay the permanent way directly upon the vaulting of this secondary tunnel, supporting the rails in cast-iron chairs with under-ribs imbedded in concrete, which is rammed in after the track has been lined up. This plan renders it unnecessary to bring other track material into the tunnel for the standard-gauge track, which can thereafter be used with greater advantage for the carriage of construction-material.

Mountain tunnel-work has been but rarely carried on under air-pressure. In a tunnel in Italy, at the beginning of the work, mud was encountered in a semi-liquid state, containing large bowlders, in which it was impracticable to use a compressed-air shield. Sections constructed on the surface, in lengths of about 18 yards, were sunk to position upon compressed-air caissons for 205 yards. The work was then carried 175 yards farther with an air-shield, and at a cost of $1060 per yard.

The time consumed in subterranean excavation by manual labor alone under primitive methods discouraged the prosecution of tunnel-work of considerable magnitude. On the Lake Fucino Tunnel,[1] 30,000 men were employed for eleven years; a work which could now be accomplished in as many months with a tithe of that labor. Even with the use of blasting powder, the Harecastle Tunnel, 1.6 miles in length and 9 feet by 6 feet in section, on the Trent & Mersey Canal, begun in 1766, was only completed in 1777.

Tunnel-work in the United States and Canada

There was but little tunnel-work in early railroad construction in the United States. The lack of capital led to the adoption of heavier gradients in crossing the mountains between the sea-coast and the Mississippi Valley than had been used in Europe. The first railroad tunnel was on the Alleghany Portage Railroad at Staple Bend, four miles east of Johnstown, 900 feet in length, and completed in 1833. The abolition of inclined planes on this route was accomplished by heavier rock-excavation, of which the most important was the tunnel at Galitzin, a mile in length. In the construction of the Baltimore & Ohio Railroad over the Alleghany Range from Cumberland to Wheeling, 201 miles, there were eleven tunnels, having a total length of 11,150 feet. Farther south, in Virginia, North and South Carolina and Georgia, State aid was freely given toward tunnel-construction through the Blue Ridge. Scarcely had such assistance been extended to the Georgia State Railroad, between Atlanta and Chattanooga, where the work was least expensive, when the Civil War interrupted further

[1] See p. 173.

progress. Subsequently, the extension was accomplished in Virginia and in North Carolina, but, to this day, work on the Rabun Gap Tunnel in South Carolina has not been resumed. The longest of these tunnels is the Big Bend, 1.23 miles, on the Chesapeake & Ohio Railway. In the Eastern States, the Bergen Hill Tunnel afforded the Erie Railroad access to New York Harbor at the beginning of the Civil War. The most important tunnel-work, however, was the Hoosac Tunnel, 4.7 miles, begun in 1855 with the methods then in vogue and completed in 1875. This was the first tunnel-work in America in which compressed-air drills and nitroglycerin were employed.

In the Mississippi Valley, a vast area was opened to railroad construction in which no heavy mountain-work was encountered until the undertaking of a transcontinental railroad made it necessary to cross the Rocky Mountains. Here the Union Pacific line was located through a favorable pass, and likewise the Southern Pacific line. It was only with the development of mining operations in this region that railroad tunnel-work in the United States became comparable in interest with that in the Alpine region of Central Europe. The ingenuity displayed in the location of the Rio Grande Southern, of the Denver & Salt Lake and of the Denver & Rio Grande roads averted the necessity for very long tunnels, even at altitudes between 10,000 and 12,000 feet. The Atchison, Topeka & Santa Fé Railway attained the Pacific Slope through the Raton Pass Tunnel, 2000 feet in length, at an altitude of 7622 feet, and on a maximum grade of 185 feet to the mile.[1] In later construction, both in the United States and in Canada, the Continental Divide has been pierced by tunnels, from two to five miles in length, in which American engineers have fully kept pace with European practice.

The increasing abundance of available capital and the desire for greater tonnage-capacity by reducing gradients has given an impetus to tunnel-work. On a railroad with present length of two thousand miles, there have been added since 1904, on branch-lines twelve tunnels, with aggregate length of 7863 feet, the longest being 4770 feet; while on main-line betterments, there have been added thirty-two tunnels, with aggregate length of 32,251 feet and a maximum length of 3291 feet.[1]

[1] Appendix IV, Table III.

TUNNELS OF RECENT CONSTRUCTION IN UNITED STATES AND CANADA

RAILROAD	NAME	LENGTH, FT.	COMPLETED
Great Northern . . .	Cascade	14,400	1905
Terminal	Seattle	5,141	1905
Ca. Clinchfield & Ohio .	Sandy Ridge	7,760	1914
Canadian Northern . .	Mount Royal	17,000	1914
Del. Lack. & Western .	Nicholson	3,630	1915
Ch. Mil. & St. Paul . .	Snoqualmie	11,890	1915
Canadian Pacific . . .	Connaught	26,400	1916

Single-track tunnels of recent construction are 16 feet wide, with clear height of 22½ feet from base of rail. Double-track tunnels have the same clear width outside and same height over center of each track. Where electric traction is used, a smaller cross-section area may be used. The single-track section of the Pennsylvania Railroad tunnels in New York City has 225 square feet of area above the track.

The Snoqualmie Tunnel through the Cascade Mountains, 60 miles east of Seattle, was opened for traffic in January, 1915. At the west end for 436 feet the work was advanced by top-heading through yielding and saturated material. The remaining distance, through harder material, was advanced by bottom-heading, 8 by 13 feet, driven at subgrade along the north side of the tunnel at 1000 to 2000 feet ahead of the bench. From fourteen to thirty 9-foot holes were drilled for each shot. Following the heading, the wings were driven to full-section width, after which the trap or stoping timbers were placed. Bench-openings were driven to full-section width at intervals of 150 feet. Although the rock was hard, it was so stratified and filled with soft talc-seams that the tunnel was lined throughout with concrete, averaging 6.1 cubic yards per linear foot.[1]

The tunnel was ventilated at each end by the exhaust method through a two-foot pipe that opened at the end of the enlarged section. An auxiliary plant at each end forced air into the heading through a ten-inch pipe.

The longest railroad tunnel in North America has been recently constructed in connection with the relocation of the Canadian Pacific Railway in British Columbia. The new line, of about 10 miles in length, replaces the line over Rogers Pass, with a reduction of 4.3 miles in distance and of 552 feet in summit-elevation, and the elimination of 2500 degrees of curvature, 4½ miles of snow-sheds and some very heavy bridging. This improvement was effected by the construction of a double-track tunnel, 26,400 feet in length, known as the Connaught Tunnel. Work on this tunnel was commenced in September, 1913, and the new line was opened for traffic on December 9, 1916.

Tunnel-work in America has usually been prosecuted on the top-center-heading method. The Snoqualmie Tunnel, on the Chicago, Milwaukee & St. Paul Railway, was excavated on the bottom-heading plan,

[1] Snoqualmie Tunnel

Average daily progress	9.5 feet
Maximum daily progress	25.0 feet
Average time between shots, divided as follows:	15.5 hours
Breaking down roof and mucking back	2½–3 hours
Setting up cross-bars, drilling and mucking out	7 hours
Taking down, clearing and shooting	1 hour
Waiting for heading to be clear of gases	1 hour

In the Grand Trunk Pacific single-track tunnel-work in sliding material, the concrete lining, 21 inches thick, averaged 5.57 cubic yards per foot of tunnel with 680 pounds of steel reinforcing rods.

driven on one side. In the Connaught Tunnel, the advance was made by a parallel drift or heading, driven fifty feet to one side of the tunnel-center, followed by the main heading, with which it was connected at intervals by cross-cuts. This pioneer-heading was 7 feet wide and 8 feet high in rock, and furnished the means during construction for air-and-water pipes and other appliances, and for carrying supplies. It was also used for conveying material from the main heading to a point in the main tunnel back of the shovels. For these purposes, it fulfills the functions of the "underheading" method, recommended by engineers in the Alpine region.

The pioneer-heading was started, at the east end, 700 feet west of the portal and 60 feet above the main-tunnel level. By this plan, 700 feet of pioneer-tunnel was saved and the soft-ground heading reduced. The heading ran nearly level until the grade of the main heading was reached. Solid rock was struck 600 feet from the entrance and, at this point, an inclined cross-cut was started into the main heading. The west pioneer-heading was started on an incline 300 feet long, from the outcrop, 700 feet east of the west portal and 150 feet above the main-heading level. This location provided dumping ground and avoided soft-ground tunneling. The headings were driven with light hammer-drills of hollow steel, with water-attachment, mounted on a light horizontal bar. The cross-cuts into the main heading were from 1500 to 2000 feet apart. There were in all 19,610 linear feet of pioneer-tunnels and twelve cross-cuts of about 40 feet each. The pioneer-tunnels were discontinued for one mile in the center of the tunnel; connection being made by the main heading only.

The main heading was located midway of the full section, eleven feet wide and nine feet high, with its bottom six feet above the subgrade. The rock consisted largely of schists, except for 1200 feet of glacial drift at the east end and of 400 feet of soft ground at the west end. No trouble was experienced from water-infiltration in the rock, and timbering was required only in the rock near the center of the mountain. Work was started January 15, 1914, and was prosecuted from both ends. The headings met December 19, 1915. The material from the enlarged section of the tunnel was excavated by shovels operated by compressed air, and was loaded directly into twelve-yard cars. The cars were hauled to the entrance of the tunnel by standard-gauge compressed-air locomotives, and thence to the dump by steam. On account of delay in driving the tunnel through the soft ground at the ends, when the main headings met, the shovels employed in the enlargement were two miles apart and did not meet until July, 1916. They advanced 27,749 linear feet in 540 days; an average of 46.1 feet per day. In the enlargement, radial shooting from the central heading was employed, instead of drilling the holes parallel with the axis of the tunnel; the holes being at an inclination of about one in four from the direction in which the tunnel was driven. About one and a half miles of the tunnel, including the soft ground at the ends, requiring concrete-lining. The tunnel was finished eleven months ahead of the contract-time at a cost of about $6,500,000, including the ventilation-system. The work was prosecuted under unusually favorable conditions as to water-infiltration and rock-pressure.[1]

RECENT TUNNEL CONSTRUCTION

	SNOQUALMIE	CONNAUGHT
Material	Black Slate Quartzite Conglomerate	Slates Quartzite Schists
Length, feet	11,890	26,400
Track	Single	Double
Finished section	352 sq. ft.	526 sq. ft.
Excavated area	517 sq. ft.	831 sq. ft.
Yards per lin. ft.	19.2 sq. ft.	30.76 sq. ft. (Solid rock, 25.0)
Heading	Bottom	Center-heading, Pioneer Drift
Heading per lin. ft.	4.0 cu. yds.	4.0–2.1 cu. yds.
Excess of excavated area, per lin. ft.	3.5 cu. yds.	3.0 cu. yds.

TUNNEL TIMBERING AND LINING

The methods of timbering in tunnel-work vary so much under different conditions that they can not here be considered within reasonable limitations. The difficulties encountered, often unexpectedly, are overcome by ingenious devices that require graphic illustration to be understood. There have been cases in which the passage through a fault has cost over $1200 a yard for timbering, the materials alone costing $200 a yard. In the recent Austrian tunnels, from the bottom-heading in advance, shafts were opened to the top of the arch and from these the top-heading was driven. From the top-heading, for a certain distance back, the full section was excavated in separate rings, each nine to eleven yards in length, in which the lining was built. The intermediate sections were then excavated and lined, the inverts put in, ring by ring, the bottom-channel constructed, and the sole of the completed section covered with concrete. In this method of excavating by individual rings, crown-timbering is used in the full section; side and intermediate sills are put in at the height of

[1] See "Methods Adopted in Construction of Connaught Tunnel," J. G. Sullivan, Chief Engineer. The Cornell Civil Engineer, January, 1917. Also "Construction Methods for Rogers Pass Tunnel," A. C. Dennis, Mem. Am. Soc. C. E., Trans. Am. Soc. C. E., December, 1917, p. 448. For other information as to recent tunnel-work in the United States and in Canada, see paper on "Tunnels" by Charles S. Churchill, Assistant to President, Norfolk & Western Railway Company, presented at a meeting of the International Engineering Congress, San Francisco, September 20–25, 1915.

the imposts on which the crown-timbering is supported, with bearers under the cross-sills where the pressure allows this to be done, and shoring up the sills and bearers by props on the tunnel-sole. This self-supporting timbering has been found to satisfy all requirements, may easily be put up by experienced miners, and requires no unnecessary excavation. A minimum amount of timber is cut to waste, much of it may be used a second time, and the timbering may be changed with safety while the masonry is carried on.

In tunnels with two inclines, where the ends are nearly level, the ruling-gradient is usually 2.5 to 3 feet per 1000, to facilitate drainage. On account of less adhesion in tunnels, the maximum gradient should be less than in the open in the proportion of 2.6 per 1000 when the outside gradient is 10 per 1000, and of 5.6 per 1000 when outside it is 25 per 1000. In tunnels with an interior summit, it should be nearer the lower entrance, if possible, so that, if the work there gets behindhand, it will not be necessary to stop the work on the other side.

Although there is great variety in the character and dimensions of masonry-lining, certain points are common to most of such work. Experience has shown that, under excessive pressure from the superincumbent mass, the cross-section should be as nearly circular as possible, with extensive use of inverts. While it is not difficult to adapt the cross-section of a double-track tunnel to the probable pressure, inverts often produce fractures in a single-track tunnel with an egg-shaped cross-section. The minimum thickness of the lining of a double-track tunnel is usually about two feet. In exceptional cases, arches have been built four feet thick, of large blocks, squared on all faces. The thicker the lining, the greater is the cross-section of excavation and the proportionate pressure. The thickness of the lining should, therefore, be diminished as far as possible by excellent material and workmanship. As rock-pressure generally begins to show only after some time has elapsed, the lining should be put in as soon as practicable.

In double-track tunnels, the drainage-channel is in the middle of the floor; in single-track tunnels, it is frequently near a side-wall, where there is no invert. In passing through sections of rock under pressure, or through saturated ground, the materials, dimensions and shape of the lining must conform to the conditions so encountered. In moderately stable ground, any building material may be used, though cement is preferable for mortar. Brick may be used to advantage, as it hastens the setting of the cement; but not in very thick arches, as the extrado joints become too wide. The brick should be well-burnt and porous, but where good stone is available, it is preferable, especially if cut on all surfaces. Rubble-work should not be used in arches, nor even in side-walls, if stone of suitable strength and size can be conveniently obtained. Where currents of air reduce the temperature below the freezing point, materials that are acted on by frost should be excluded. Reinforced concrete has become valuable for tunnel-lining where the masonry is exposed to great pressure. As failure in the vaulting generally takes place near the concave surface, the reinforcement should be so arranged as to distribute the pressure on the inner third of the block, over its whole cross-section.

It is difficult to make a tunnel-lining absolutely impermeable by water. Usually the extrados is covered with dry stone laid on cement. The water then collects at the imposts and is led to the main drain by channels in the walls or outside of them. Even under slight water-pressure, this method is not satisfactory, but may be improved by covering the layer of cement with tarred sheets carefully bricked in. The best method is the injection of cement behind the masonry with compressed air. Where this is done, the layer of dry stone should not be used, as the voids require a large quantity of cement. The injection should be made upward from the lower part of the lining. Catch-water drains must be provided to collect any spring-water, as it will waste away much of the cement. They should be watertight, to prevent their obstruction by extraneous matter. Water containing sulphates should be carefully excluded, to prevent chemical reaction with the mortar, which has been found completely decomposed by water containing a hundred grains to the gallon of calcium sulphate. In this case, a layer of concrete was covered with one of asphalt, which is a slow and costly measure. The use of mechanical appliances for the drainage of a completed tunnel should be reduced, as far as practicable, by resort to gravity. Where such drainage can not be provided directly, the water may be collected into pits and pumped into the drainage-ways.

Bronze-studs should be placed in the lining and their position carefully determined in order to test its stability under pressure. Holes should be drilled through the masonry wherever there has been an inflow of water. Any sudden variation in the normal infiltration should be immediately investigated. It is of doubtful advantage to finish the arch before the side-walls, as in top-heading. Where the supporting material is apparently stable, accidents frequently happen from the imposts giving way. Even in very hard rock, the removal of the underlying material exposes the arch-masonry to serious disturbance and, however much care may be taken in blasting, the lining of the arch is often damaged.

The restoration of a lining that has failed under pressure may not cause serious obstruction in a double-track tunnel, as a single track can usually be maintained through it under a temporary roof. Where this can not be done, resort must be had to extraordinary expedients. In some cases, the bottom of the tunnel has been lowered to make room for the work overhead. Iron beams serve a useful purpose, and reinforced concrete may facilitate the prosecution of such work. As a general rule, the work should be separated from passing trains by a partition-wall, or it may be carried on outside of the lining. In view of the difficulties encountered in the restoration of a defective lining and the loss from obstructed traffic, it is of the first importance that the original masonry should be carefully planned and thoroughly well executed.

Cost of Single-track and Double-track Tunnels

From the statistics given in Appendix IV, Table IV, it appears that the completed cost of single-track tunnels in Europe, over a mile in length and under six miles, has been from $200 to $300 per linear yard and, in exceptional cases, $432 and $560 per yard. The cost of the Simplon Tunnel, 12.2 miles, including the ventilating passage, was about $677 per yard. Double-track tunnels between one and five miles in length have usually cost between $300 and $400 per yard and, in exceptional cases, from $540 to $849 per yard. The St. Gotthard Tunnel, 9.2 miles, cost $749 per yard, and the Arlberg Tunnel, 6.4 miles, $823 per yard. The dimensions of some of these tunnels are given in Appendix IV, Table II.

It is usually assumed that two single-track tunnels will cost about 30 per cent. more than one double-track tunnel in the same location. It is of doubtful economy to construct a very long tunnel unless the traffic warrants a double-track. Though the St. Gotthard Tunnel was built for two tracks, at first only one was used. But, within the first year of operation, the second track was needed. In the Simplon Tunnel, where the increase in freight-traffic was slower, the want of a second track was felt after three years of operation. The saving in interest can only balance the extra cost of a second single-track tunnel after ten years have elapsed. Under ordinary operating conditions, there must be intermediate passing places in long tunnels, which are expensive.

Economy in Time and Labor of Modern Tunneling Methods

The cost of tunnel-work and the time consumed in its prosecution have become greatly diminished with the introduction of machine-drills and high explosives. In the Alpine tunnels, the advance with machines has been from three to ten times greater where the hand-work averaged less than a yard a day, and, on an average, seven times as much. The difference diminishes as the hand-work exceeds a yard a day. At the rate of only a three times greater advance, it was found that a cubic meter, or 1.308 cubic yards, was excavated by hand at about three-fourths the cost of machine-work. This rate of cost, however, must vary with the relative cost of labor, and the time saved is an important matter. In very hard rock, the average advance by hand-drilling does not exceed a rate of one meter (3 feet 3⅜ inches) per day. In the Simplon Tunnel, with machine-drilling, the average advance in each period of three months was about 656 yards, with a daily maximum of 26 feet 3 inches. With hand-drilling the daily advance in nine instances averaged less than a yard; in fourteen instances, less than two yards and, only under exceptional conditions, as much as 2½, 3½ and 4 yards. With machine-drilling, the daily average in four instances was less than three yards; in five, less than four yards; in six, less than five yards and in one case, 6.08 yards. In bottom-headings, machine-drills are generally used only in the main heading; their use in different working places is mainly a question of power. In a long tunnel where water-power is available, it is advisable to do all the breaking-out work by machines, especially with the increasing cost of manual labor.[1]

In machine-drilling, percussion-machines are generally used. The rotary cutters employed in coal-mining have not given satisfaction in rock-work. Compressed-air machines have been found preferable to those operated by hydraulic power on account of their simpler construction, with less loss of time for repairs and with better working results. Percussion-hammers, operated by compressed air through flexible hose, may be used to advantage where it is inconvenient to use machines. The compressed-air machines are of two types; either the drill is advanced automatically or by hand. Each has its advantages and its disadvantages. Electrically operated machines are also in use. There are three kinds, the solenoid, the crank-and-spring and the rotary type. The solenoid apparatus is the simplest, but it quickly becomes hot and it is not possible to withdraw the drill if it becomes jammed. It was therefore abandoned in the construction of the Jungfrau Tunnel, where the crank-and-spring machines gave more satisfactory results, but were eventually given up because of the frequent repairs. With an advance of 1.2 meters (about 4 feet) per set of fifteen holes, these machines averaged about three hours, and the compressed-air drills from two to two-and-a-half hours. The electric rotary machines have been but little used in tunnel-work, as it has not been practicable to obtain the pressure required for very hard rock without excessive friction. The electro-pneumatic percussion drill, combining the portable compressor and the air-drill in one apparatus, has proved the most efficient of the drilling machines.

Tunnel-working has been facilitated by the substitution of petroleum

[1] Comparative Progress of Tunnel-work

Tunnel	Date	Length in Miles	Section	Average Daily Progress
Mont Cenis	1857–1871	7.98	26′3″ × 24′7″	2.57 lin. yds.
St. Gotthard	1872–1881	9.14	26′3″ × 24′7″	6.01 lin. yds.
Arlberg	1180–1891	6.36	25′3″	9.07 lin. yds.
Simplon	1898–1905	12.26	16′5″ × 19′6″	11.63 lin. yds.

Machine-drilling introduced at Mont Cenis in 1861. With hand-labor 9 inches per day; with compressed-air drills, 45 inches per day.

St. Gotthard. Compressed-air drills.

and acetylene lamps for the ordinary miner's lamps, and by electric lighting in the completed archway. It is advisable to use safety-lamps if there be apprehension of fire-damp; accidents from this cause have occurred, even where its presence had not been previously indicated by geological conditions.

With machine-drilling, intermediate shafts are not of much advantage for working purposes within 1500 to 2000 yards of the nearest tunnel-ends. In solid rock, as much time is required to sink a shaft 300 feet with machines as to drive a heading 1500 to 2000 yards. Headings are driven more slowly from a shaft, and material is handled through it at much greater cost. Sinking a shaft in water-bearing strata may lead to disturbance of the superincumbent mass, and add to the difficulty in starting the headings from it. Inclined shafts are preferable to vertical shafts, as the former can be sunk four times as rapidly. It has been found that four times the quantity of material can be removed through an inclined shaft as through a vertical one, and the rate of progress at the working faces is materially better.

Much time is lost, in drilling, by clearing away the excavated material, amounting in different cases from an equal number of hours to nearly double as many, including the time required for putting in the blasts and for firing them. Attempts to reduce this loss of time by the aid of mechanism have not so far been satisfactory. In the removal of excavated material, mechanical traction has superseded animal power in the completed portion of the tunnel. In a top-heading it is stopped at the first ramp, where the material is dumped into the cars from hand-trucks, or the cars are run down into the train. Where the rock-pressure has made it difficult to provide passing-places of sufficient width, the empty cars have been hoisted into excavations above and the loaded cars passed beneath them. In tunnels with a bottom-heading, compressed-air locomotives clear away the broken rock from the working-faces, but this requires powerful compressors. Tunnel-traction has also been performed with locomotives actuated by superheated water. Steam should not be used in the working-section of an artificially ventilated tunnel. It is a waste to pump air into a tunnel at great expense and then to vitiate it unnecessarily. As electric traction has now come into use in the operation of long tunnels, it should also be used in the completed portion of such a tunnel during construction, but the trolley wire can not be taken beyond it. In any tunnel-installation, ample power should be provided for all requirements and sufficient water-power is usually available for hydro-electric plants.

Ventilation of Tunnels

Tunnel-ventilation gives occasion for serious problems during construction, as well as in after-operation. They become more difficult of solution at the great elevations at which long mountain-tunnels are driven.

At such altitudes, the rarity of the atmosphere and the external temperature are conditions to be considered as affecting the working forces and the requirement for an artificial supply of air. Rock-temperature is also an important consideration. The temperature of the earth is constant at a depth of 65 to 175 feet and about 2° F. higher than the mean annual surface-temperature. From experience in driving deep tunnels, it is inferred that, below that depth, the temperature increases one degree for each 80 feet under a valley, for each 100 feet under a plain and for each 150 to 200 feet under a mountain.

In the Jungfrau Tunnel, at an elevation of 10,500 feet, and where the rock was 1640 feet thick, its temperature at the working face was 39° F. Blasting raised the air-temperature to 55°, but, in the intervals, the air through the ventilators and from the drilling machines reduced it to 35°. Under these conditions, the men felt no ill effect from the altitude.

In the St. Gotthard Tunnel, the highest temperature was 87° F. and accordingly it was calculated that the highest temperature in the Simplon Tunnel would be about 107°. In fact, on the north side the temperature reached 137°, while on the south side it was from 18° to 36° below the predicted temperature. In the St. Gotthard Tunnel, the temperature rose a degree for each 160 to 180 feet in depth while, in the Simplon Tunnel, it rose at the same rate for each 120 to 150 feet. The erroneous prediction was due to insufficient data as to the mean annual surface-temperature, and to the cooling effect of the numerous springs encountered in the St. Gotthard Tunnel. To this cause was also attributed the lower temperature on the south side of the Simplon Tunnel. It was subsequently ascertained that the heat of the earth passes to the surface quicker through strata which dip considerably than through horizontal strata.

Artificial ventilation becomes necessary for efficient work when the temperature in the tunnel exceeds 77° F. Within certain limits of distance, ventilation is much improved when compressed air is used as a motive force, though the exhaust from the drills alone has been found insufficient for this purpose. If a ventilating shaft communicates with the heading, it may be equipped with an exhaust-fan. As the length of the tunnel approaches three miles, an independent source of ventilation becomes indispensable for an ample supply of fresh air, and resort must be had to blowers and conduits.

A ventilation-plant should be planned for operation after the tunnel has been opened for traffic. Its economic efficiency for this purpose depends not only upon the capacity of the blowing apparatus, but also upon the relation of the cross-section of the conduit to its length. The resistance offered to the passage of air through a pipe varies inversely as the fifth power of its diameter.

In the Simplon Tunnel, the minimum quantity of fresh air required for a working-section of 1000 yards was fixed at 1060 cubic feet per second.

There was not room in the heading for pipes over 20 inches in diameter, and to furnish such a volume of air through such a pipe would require about 50,000 horse-power; whereas the same service could be rendered with 18 horse-power through a conduit of 8 feet 3 inches in diameter. For this reason, the ventilation was effected through a drift-way of 65 to 75 square feet in cross-section, driven at a distance of 56 feet from the main tunnel.

Sufficient ventilation was provided at the working-faces with 883 cubic feet of air per second, but the current could not exceed a velocity of from 12 to 15 feet per second without inconvenience from draughts and dust. For this purpose, a secondary apparatus was installed of small turbines and blowers, with water-jet blowers supplying 53 cubic feet of air per second. The installation was operated with 10 horse-power from the high-pressure water-supply to the drilling-machines. By these means, the temperature of the air was kept below 77° F., so long as the rock-temperature was below 95°. When this temperature was exceeded, the air-temperature was reduced by spraying the rock from a pipe about 10 inches in diameter, supplying 22 gallons per second at an outside temperature of 34° F. in winter, and of 46° in summer. This pipe was insulated by charcoal in another pipe, and delivered the supply at 46° to 59°. With the highest rock-temperature experienced (133° F.) and an air-supply of 883 cubic feet per second, the spray was delivered at 50°. Under these conditions, the temperature within the tunnel at five miles from the entrance was maintained below 77°. In the more recently constructed Austrian tunnels, 206 cubic feet of air per second was supplied through piping of 2 feet 3¼ inches diameter in the finished portion and of 1 foot 7⅝ inches diameter in the headings, with 360 horse-power.

The natural ventilation, which may have been sufficient during construction, may be inadequate to meet the requirements in after-operation. This depends in some measure on the difference in height between the tunnel-entrances, their situation as to environment, and on the direction and strength of the prevailing winds. Natural ventilation is usually sufficient in double-track tunnels and in single-track tunnels electrically operated; except in the Simplon Tunnel, which is on steep inclines where the heat becomes oppressive at the summit. In the Cochem Tunnel in Prussia, 2.6 miles in length and double-track, artificial ventilation was required after the trains exceeded seventy per day. In an investigation of 84 single-track tunnels in Italy, twelve had deficient ventilation normally and sixteen occasionally. In the tunnels with normally defective ventilation, double-heading was used on gradients exceeding 10 per 1000, and the number of trains in both directions in twenty-four hours was not less than twenty-six. In France, the natural ventilation was insufficient in four single-track tunnels and in one double-track tunnel. In Grand-Brion Tunnel (1285 yards, single-track) on the Grenoble line, where double-heading was in use, it was found impracticable to use triple-heading.

The movement of air in a single-track tunnel becomes reduced with the length of the tunnel. As a consequence, the air may be less vitiated in the longer tunnels, yet it causes greater suffering because of the longer exposure.[1] In a single-track tunnel with a continuous grade and not more than half a mile in length, the atmosphere became oppressive when the number of trains was over ten in twenty-four hours, heavily loaded up-hill.

In some short up-hill tunnels, in the most unfavorable months, a carbonic-acid content was found in the pusher-cab of 4.6 parts per 1000, and of carbonic oxide up to 8.1 parts, also sulphurous acid. The temperature in the cab often ran up to 99° F. and even as high as 140° in the summer months, when there was no wind. Where this is the case, pushers should be dispensed with, as far as possible, by the use of more powerful locomotives, and even by reducing the gross weight of the trains. Slipping is thus diminished and the time shortened in the tunnel. Coal containing sulphur should not be used, nor coke, as it produces large quantities of carbonic oxide and of hydro-carbons. Oil-firing produces no sulphurous gases and but little smoke and, if the train be stopped, the combustion may be cut off. But the crew suffers from the higher temperature of the gases and, if there be an excess of oil, the smoke is worse than with coal. Rather successful results have been obtained by drawing air from the bottom of the tunnel and blowing it into the cab with a small blower, operated by a steam turbine on the locomotive; the air is pumped through a strainer and the asphyxiating gases absorbed. This expedient, however, affords no relief to the track-hands, and, under such conditions, adequate improvement in a foul tunnel can only be effected by electric traction or by a modern ventilation-plant.

If the volume of carbonic gases in the air in proportion to the quantity of coal consumed be taken as a measure of vitiation, the relative values corresponding to good and bad ventilation may be expressed numerically as 4 and 11 parts per 1000, respectively. It has been proposed to establish 6 parts per 1000 as the limit of vitiation with freight-trains, and 3 per 1000 in the case of passenger-trains.[2]

Where there is an interior summit, the vitiated air is withdrawn at that point through a duct connected with exhaust-fans at the ends of the tunnel;

[1] The movement of a train in a tunnel 274 yards in length produced a current of 24 feet per second, but only at half that rate in a tunnel over three miles long.

[2] Volume of Air Required for Ventilation. Assuming that 29 cubic feet of poisonous gases are produced for each pound of coal consumed per mile, then in order to maintain the atmosphere in a tunnel at 2 parts of carbon dioxide per 1000, there will be required 29 times the number of pounds of coal consumed multiplied by 500 and divided by the intervals in minutes between passing trains. For example, in a tunnel one mile in length with fuel consumed at the rate of 32 pounds per mile and a train passing in each direction every five minutes,

$$\frac{32 \times 29 \times 500}{2\frac{1}{2}} = 185{,}600 \text{ cubic feet per minute, the volume of fresh air required.}$$

Enc. Brit. XXVII, 409.

fresh air being supplied through the portals. This method, known as the "Guibal" system, is also in use at the Severn and Mersey tunnels, where the air is withdrawn at the point at which descending grades meet and the heavier gases become concentrated. At the Mersey tunnel, the top of the exhaust-opening was parallel with the fan-shaft. As each blade of the fan passed the opening, there was a momentary stoppage of the air-current which imparted a vibratory motion to the fan that was injurious to the apparatus and gave a tremor to the atmosphere, which affected the neighborhood. This was obviated by cutting a V-shaped opening in the shutter at the chimney-entrance; thus gradually decreasing the aperture and allowing the air to pass into the chimney in a continuous current instead of intermittently.

The exhaust-system is unsuited to a tunnel on an ascending grade. Here the process should be reversed, and air forced into the tunnel under pressure in a closed chamber at the upper portal, thus causing an induced current in the open tunnel against an ascending train and driving the products of combustion to the rear of the train instead of following it in its ascent.[1] In providing for artificial ventilation on this principle, consideration must be given to the resistance offered by the current engendered by the ascending train which, in a single-track tunnel, is from two to three times that produced in the open. In a double-track tunnel, it is of little effect. In tunnels with gentle gradients and heavy traffic, an artificial current of ten feet per second has been found sufficient, regardless of the direction of the train.[2]

Leaky conduits materially reduce the mechanical efficiency of a ventilating plant. In a conduit with well-made joints, its mechanical efficiency was 82 per cent. of its volumetric efficiency in a length of 1½ miles, and but 50 per cent. in a length of 3 miles. The loss by leakage was 0.5 per cent. per 100 yards of conduit. The conduits should be installed during the prosecution of the tunnel-work. In a double-track tunnel, it should be under the tunnel. Where electric traction is used, the tunnel can be ventilated by putting in a shutter midway in the underheading. When the shutter is closed, air can be blown in at each entrance and escape

[1] Enc. Brit. XXVII, 407.

[2] Air Resistance in Simplon Tunnel

Clear Cross-section, 250 square feet

	Speed in Miles per Hour (Resistance in pounds per ton of 2240 lb.)		
	31	37	43½
Running in direction of current . . .	11.20	14.34	17.92
In opposite direction	15.68	21.73	28.00
In open air	7.39	9.18	11.20

through adjustable openings. Where the traffic is almost incessant, no plan of ventilation yet devised has proved satisfactory under all conditions. If a tunnel exceed 1½ miles in length, it may be advisable to build it double-track; though with an interior summit it may even then require artificial ventilation. But if artificial ventilation be required in a single-track tunnel exceeding 2 miles in length, the installation of the necessary plant, with the working expenses capitalized, may approximate the original cost of a double-track tunnel.

The "Saccardo" system of ventilation, invented about 1896, is in general use in Europe, except in the Simplon Tunnel. In this system, an annular conduit occupies the space between the masonry-lining and the loading-gauge at the portals. In long and steep tunnels, a current of air is produced in the opposite direction to that of the passing train, of sufficient volume and velocity to overcome the air-current which accompanies the train, and, in addition, to neutralize any natural current in the same direction. This system has two defects; the great quantity of power required, and its low efficiency, which could be increased from ten to fifteen per cent. if the apparatus at the entrance to a tunnel were arranged both to blow in the air and to exhaust it.

In the Ronco Tunnel (double-track and four miles in length) between Genoa and Milan, exhaust-fans, 18 feet 10 inches in diameter and operated with 700 horse-power, produced a descending current at 10 feet per second and an ascending current at the same rate, which do not, however, free the tunnel from smoke sufficiently to render visible the block-signals in the middle of the tunnel. Two additional fans were therefore installed on either side of the signals; one of 125 horse-power driving air toward the upper end, and the other of 50 horse-power blowing in the opposite direction. The total cost of these installations was about $150,000.

In the Pracchia Tunnel (single-track and 1.7 miles in length on a steep grade) between Bologna and Pistoia, it was proposed to neutralize the current of air produced by an ascending train, and then to sweep out the tunnel by a current at 10 feet per second. With a double-header, at a speed of 15½ feet per second, the power required for this purpose was as follows:

Natural Current in Same Direction	Water-pressure		Fan-revolutions per Minute	Horse-power
	In Tunnel	At Outlet of Injection		
None	9.84	14.17	86	103
10 feet per sec. . .	12.28	18.82	99	147

With a train moving at a speed of 33 feet per second, 122 horse-power was required to neutralize the accompanying current, and 233 horse-power to produce a current of 6½ feet per second in the opposite direction. The original installation of 320 horse-power was increased to 440 horse-power, in order to obtain satisfactory results.

At the Giovi Tunnel (double-track, 2 miles in length) on a gradient of 30 per 1000, near the Ronco Tunnel, fans were installed at the upper end, 20 feet in diameter and producing a current of 20 cubic feet per second, when running at 90 revolutions per minute. With 29 trains ascending daily, 23 triple-headers and 6 double-headers, on an average interval of 19 minutes, the air is breathable, but it requires from 20 to 25 minutes to clear the tunnel of smoke.

At the St. Gotthard Tunnel (double-track, 9.2 miles in length) 4415 cubic feet of air are forced in per second. When assisted by a natural current of 6½ feet per second, 750 horse-power is required to reduce the vitiation to 6 per 1000 on the standard scale. The ratio of the work done in moving the air in the tunnel to the sum of the power developed at the motor and the resistance opposed to the train by the assisting current, is from 0.51 to 0.57, as against 0.40 at Pracchia.

In the Simplon Tunnel, ventilation is provided by closing with a movable screen or curtain the entrance near which the ventilators are situated, and then changing the air, either by exhaustion or by blowing in fresh air. The curtains are of heavy canvas on iron frames, balanced by counterweights and moving on rollers in grooved channels. They are raised by electric motors operated from a signal-cabin where approaching trains are indicated by automatic rail-contacts. Other signals notify the motorman whether the curtain is up or down. In case of misunderstanding, the tractor could tear through the curtain without causing serious damage. The installation at each entrance consists of two fans for blowing or for exhaust, each 12 feet 3 inches in diameter and actuated by a turbine of 200 horse-power. They are operated either in series for pressure, or in parallel for volume. The air is blown in at the north entrance and exhausted at the south entrance, with a volume of 3178 cubic feet per second at 275 revolutions per minute, which is sufficient for electric traction. The highest temperature is 80° to 82° F. in the south end, and 77° to 79° in the middle of the tunnel.[1]

Recently Built Tunnels in America and their Ventilation

Artificial ventilation of tunnels in America has followed about the same course as in Europe.[2] An improvement upon the "Saccardo" system has been devised by Mr. Charles S. Churchill, while Chief Engineer of

[1] Most of the information as to European practice in tunnel construction and operation has been obtained from the Proceedings of the International Railway Congress at Berne, in 1910, in which the subject is considered at great length and with ample illustrations. For a list of the principal tunnels in Europe, see Appendix IV, Tables II and IV.

[2] For a list of artificially ventilated tunnels in the United States, see Appendix IV, Table V.

the Norfolk & Western Railway, and has been generally adopted. It was an objection to the Saccardo system that the air-conduit surrounded all the sectional area of the tunnel at the portal and decreased the clearance limitations at that point. In the Churchill system, the air-conduit or nozzle is constructed outside of the portal in funnel-form, tapering down to its required sectional area about fifty feet from the entrance of the tunnel. This conduit therefore serves as a blower nozzle, through which fresh air may be forced into the tunnel without contracting its sectional area.

The Elkhorn Tunnel on the Norfolk & Western Railway, and the first installation of this system, affords a typical example of its successful application. This tunnel is single-track, 3000 feet in length, on a gradient of 1.4 per cent. or 1 in 71, and with a sectional area of 235 square feet. Fresh air is delivered at the lower end at the rate of 400,000 cubic feet per minute at a velocity of 1700 feet per minute. The coal-traffic through the tunnel in recent years was handled by two Mallet locomotives, one acting as pusher, at a speed of seven to eight miles an hour. The trains were from 50 to 60 cars, with a gross weight of about 3500 tons. These locomotives consumed 173 pounds of coal per minute, emitting 43,000 cubic feet of gas; including 496 cubic feet of carbon monoxide, 4253 cubic feet of carbon dioxide and 34,500 cubic feet of nitrogen. The bad and the inert gases in combination amounted to 21,000 cubic feet per minute during the 4½ minutes that the train was passing through the tunnel. As the ventilation was conducted, the smoke of the first locomotive as well as that of the pusher was forced ahead of the train, so that the men on the locomotives experienced no discomfort and the tunnel was clear of smoke as the train passed out. The increase of traffic, accompanied by the use of heavier locomotives, compelled a resort to artificial ventilation also in the Horse Shoe Tunnel on the same line, though on a much easier grade. This tunnel is single-track and 3291 feet in length, with sectional area of 300 square feet. The ventilation is by two electric fans at the upper end, supplying 540,000 cubic feet of air per minute.

The Big Bend Tunnel, on the Chesapeake & Ohio Railway, is single-track, 6500 feet in length, with an ascending grade of 21 feet to the mile for two-thirds of its length from the west end and a descending grade of 4 feet per mile thereafter. It is ventilated by two blowing-fans, each of 14 feet diameter and 7-foot face. They are designed to deliver a current of air at 1600 feet per minute, but with 200 horse-power only 1200 feet per minute could be attained. These fans are placed at the east end of the tunnel and blow against the heavily loaded trains instead of blowing with them, as at the Elkhorn Tunnel. Owing to the length of the Big Bend Tunnel, if the fans had been placed at the west end, the speed of the trains would have had to be less than that of the air-current, say 1000 feet per minute in order that the smoke might be blown ahead of the train. Then, only one train could have been passed through in each 15-minute interval, as the block including the tunnel is two miles in length. But with the fans at the east end, it is practicable to maintain a speed of 2000 feet per minute with a train interval of 7 to 8 minutes.[1]

The Connaught Tunnel, on the Canadian Pacific Railway, is ventilated by fans at the higher end, which are driven by Diesel engines, each of 500 rated horse-power at sea-level. They are operated only when a train is ascending the tunnel, driving fresh air against the train and for a sufficient length of time thereafter to clear the tunnel of gas. As oil is used for fuel on this section, the fire can be shut off in case of an emergency stop and there is no production of carbon monoxide.[2]

The cost of an installation on this plan has been from $25,000 to $40,000. Higher air-velocities are used than heretofore in European practice, which serves to keep the track in dryer condition. In many installations, the spacing of the trains requires the operation of the fans at full-speed only at short intervals. A single-track tunnel a mile in length is cleared in 4.8 minutes by fresh air supplied at a velocity of 1100 feet per minute and in 3.3 minutes at a velocity of 1600 feet per minute. In a double-track tunnel of the same length and of a sectional area of 450 square feet, with trains at 15 miles an hour, spaced at 5-minute intervals, the total emission from the stack of a heavy locomotive during the four minutes of its passage will amount to 43,000 cubic feet within the total contents of the tunnel, which is about 2,400,000 cubic feet. Under these conditions, the tunnel should be cleared in four minutes with a delivery of 600,000 cubic feet of fresh air per minute at a velocity within the limit of 1300 feet per minute. The tunnel would, therefore, be practically cleared of smoke within the five-minute intervals of passing trains and, even if this interval were somewhat diminished with increasing traffic, the gases remaining in the tunnel would be so greatly diluted as to cause but little discomfort in operation. The increasing use of electric traction in badly ventilated tunnels will materially lessen the necessity for artificial ventilation.[3]

Subaqueous Tunneling. Examples of Construction

The progress made in the art of tunneling was in course of time applied to passing beneath broad rivers and estuaries, instead of bridging them. The earliest example was the underground passage of the Thames River; commenced in 1823 as a footway, but subsequently enlarged as a double-track railway tunnel. This work was made memorable by the employment of a rectangular excavating shield for driving the tunnel through the

[1] Railroad Gazette, February 20, 1893.

[2] See "Ventilation of the Connaught Tunnel," J. G. Sullivan, Chief Engineer. The Cornell Engineer, February, 1917.

[3] The information as to artificial tunnel ventilation in America has been obtained from a paper by Mr. Charles S. Churchill, M. Inst. C. E., on "Ventilation of Tunnels and Subways in America," published in the Proceedings of the Institute of Civil Engineers, Vol. CC, 1914–1915, Part II.

silty river-bed, invented in 1818 by Sir Marc Isambard Brunel, father of I. K. Brunel. This shield was of iron, 36 feet wide and 22 feet high, covering the face of the work. It was of cellular construction with twelve cells, each 3 feet wide and 22 feet high, subdivided horizontally into three cells, closed with sliding shutters. The shield was forced against the silt by hydraulic jacks and the oozy material was excavated with safety, as it was removed in such small quantities that the mass could be kept under control; though the workmen's candles were frequently extinguished by the occluded gases. The shield was moved ahead through an iron tube in which the masonry-lining followed. Depressions formed in the bed of the river were filled up with clay, but the water broke through in such quantities in May, 1827, that the work was stopped and not renewed until 1836. It was completed on March 25, 1843, at an average cost of $6500 per linear yard. The work could have been executed more cheaply and expeditiously, had it been projected on a level fifteen feet lower, where it would have been driven through the stratum of London clay, which is impervious to water.

In 1865, P. W. Barlow patented a circular shield in connection with a cast-iron lining of the completed tunnel back of the shield, and, in 1869, associated with J. H. Greathead, he constructed a subway of this character under the Thames at Tower Hill. A vertical shaft, 10 feet in diameter, was sunk for 60 feet into the clay stratum on each bank of the river, and these shafts were connected by a tube 1350 feet in length and of seven feet internal diameter. The shield of $\frac{1}{2}$-inch plates was slightly tapering, with the larger diameter forward, to reduce the skin friction. As the shield advanced, the space around the tube was grouted by compressed air. In the same year, A. E. Beach patented in the United States the use of hydraulic rams abutting against the lining of the completed tunnel for pushing the shield forward, and utilized his invention in 1873 in an attempt to build a subway under Broadway in New York City.[1]

The next important subaqueous construction was that of the Mersey River Tunnel between Liverpool and Birkenhead. After preliminary operations in 1879, the main tunnel was begun in August, 1881, and opened for traffic in January, 1886. It is about 4000 feet in length and 26 feet in width, with a brick lining 2.25 feet in thickness, and was driven at a depth of 180 feet below the level of the quay. It was intended to keep the bore in solid rock, but, as with the Kandersteg Tunnel on the Loetschberg line,[2] the geological predictions were at fault. For a distance of 200 feet, the crown of the tunnel was six to seven feet above the rock, in the ancient river-bed filled with glacial drift, bowlders, clay and sand, under a depth of 100 feet of water. With the aid of powerful pumping machinery, this part of the work was accomplished without the use of an excavating shield or of compressed air. The tunnel was operated by steam for twenty years

[1] See p. 208. [2] See p. 175.

before the introduction of electric traction.[1] The subway connecting East Boston with the city proper, 1.4 miles in length, of which 3400 feet is under the harbor, is the first important example of a shield-built, monolithic concrete arch. The earliest subaqueous tunnel in America was built in 1889–1890, to carry the Grand Trunk Railway under the St. Clair River between Sarnia and Port Huron, and is 1.13 miles in length between portals.

In 1904–1905, the New York Rapid Transit System was carried under the Harlem River through tubes, 15 feet in diameter and 400 feet in length. The top of the tunnel is 28 feet below high water and 3 feet below the river-bed. McBean, the subcontractor, who afterward built the Subway Tunnel under the same stream,[2] here adopted a novel and ingenious method of construction. A trench was dredged to within seven or eight feet of the required depth and a space inclosed of the width of the tunnel from shore to mid-stream with sheet-piling cut off two feet above the outside top height of the tunnel. On this piling was tightly fitted a temporary flat timber-roof, three feet thick, covered with five feet of dredged mud. Water was expelled from this chamber by compressed air, and the lower half of the tunnel was built inside of concrete, surrounded by a cast-iron shell. The sheet-piling was then cut off at mid-height of the tunnel, and the upper part of the tunnel-shell was lowered in sections through the water to serve as a roof until the upper half was completed.

Compressed Air Method

A great advance in the construction of subaqueous tunnels followed upon the application of the experience gained in the use of compressed air for bridge-foundations. The caisson or air-lock was utilized horizontally instead of vertically, in connection with the excavating shield, and with far-reaching consequences. It is said to have been so employed in Antwerp, in 1879, but it was brought into more prominent notice in the same year in the construction of a tunnel under the Hudson River from Hoboken to New York City. This enterprise was projected by D. C. Haskins, financed by British capitalists, and was planned with two tubes of brick-masonry, 16 by 18 feet. When the northerly tube had been driven about 1200 feet from the New Jersey shore, the air blew through the silt, twenty men were drowned, the tube filled with water and the work was temporarily abandoned.

In 1886, the City & South London Railway was carried beneath the Thames. Because of the exorbitant demands for a site on the river-bank, the headings of the tunnel were begun from a cribwork in the middle of the river, from which shafts of cast-iron rings, 13 feet in diameter, were sunk

[1] The system of drainage in this tunnel is described on page 174 (note), and that of its ventilation on page 190.

[2] See p. 205.

into the clay. Here the hoisting machinery was placed and material expeditiously removed and delivered by barges. The land-damages for the approaches under the shores were also lessened by superimposing one tube over the other. These tubes were 10½ feet in diameter, of cast-iron plates nearly an inch thick, in rings of 20 inches in length connected by three-inch flanges. Where sand and gravel were encountered, the air-lock was used; but the shield was not used as an aid in excavation until it was found that the work could be greatly expedited by arming its cutting edge with projections that broke up the clay, as it was forced forward by the hydraulic jacks; and an advance was attained of 13 to 16 feet in twenty-four hours. The doorway in the face of the shield was placed near the bottom, so that, in event of a sudden inflow of water, the air-pressure would still maintain a breathing space in the upper part of the shield.

The Baker Street & Waterloo Railway, opened in March, 1906, was also carried under the Thames from a cribwork in the river. This tunnel, of two tubes, 12 feet internal diameter and 23 feet apart, was driven through a bed of sand and gravel in a deep depression in the clay, of which no indication was given in sinking the foundations of the Charing Cross Railway bridge, 250 feet away. As the shield advanced, it was overloaded with clay, and the air-pressure was varied from 21 to 35 pounds per square inch, to suit the height of the tide. Blow-out pipes were carried into the shield, to sweep out the vitiated air, before it became mixed with the tunnel-air between the air-lock and the shield. The Glasgow District Tunnel, 1891–1896, was carried beneath the Clyde under air-pressure. Before it had advanced 80 feet, and only 13 feet under the river bed, it had been blown out ten times; but the work was continued by filling the holes with clay.

With the experience thus gained in the use of compressed air, work on the Hudson River Tunnel was resumed in 1890 by British engineers, and extended for 1800 feet, when it was again suspended because of financial difficulties. In 1901, the company was reorganized by W. G. McAdoo, as the Hudson & Manhattan Railroad Company. An iron lining was substituted for the brickwork, a parallel tube was added, and the tunnel was opened for traffic on February 25, 1908, as an electric railway connecting the Delaware, Lackawanna & Western Railway station with stations on Sixth Avenue at Fourteenth and Nineteenth streets. The successful inauguration of this tunnel was an incentive to undertaking similar work, to facilitate the entrance of the Pennsylvania Railroad into New York City, which had been hitherto impracticable. From this beginning there have resulted examples of underground engineering in and around that city, unequaled elsewhere for the ingenuity displayed in design and for celerity of construction under unusually difficult conditions. In subaqueous tunnels alone, there are the original twin tubes of the Hudson & Manhattan Railroad, its second pair of tunnels from Cortlandt Street to Jersey City, subsequently continued to a junction with the Pennsylvania

Railroad tracks at Marion; the two tunnels of the Pennsylvania Railroad under the Hudson River and under East River to a connection with the Long Island Railroad; the "Belmont" Tunnel under East River; the two twin tubes of the New York Subway under East River and one pair under Harlem River; also a projected tunnel under East River to relieve the traffic over the Queensboro Bridge.

In connection with these subaqueous works there are three independent systems of subways in New York City; one from the Cortlandt Street terminal of the Hudson & Manhattan Railroad to a connection with the original Hoboken-Tunnel line under Sixth Avenue and beyond Nineteenth Street to Thirty-third Street; the Pennsylvania Railroad subway from its Hudson River tunnel to its city terminal and beyond to its East River tunnels; and the municipal system of subways as originally operated, and as now being extended to connection through its East River tunnels to Long Island, and through its Harlem River tunnel into the Bronx and beyond. The Hudson & Manhattan Railroad Company has also built a connection beneath the New Jersey shore between its terminals in Hoboken and in Jersey City, and, jointly with the Pennsylvania Railroad Company, is operating a suburban line from its Cortlandt-Street terminal to a transfer station in the outskirts of Newark for a connection with the main-line trains of that company, and over an independent line beyond into Newark.[1]

The tunnels of the Hudson & Manhattan Railroad were driven through the silt simply by displacing it. Instead of permitting the material to enter the openings, the shield was pushed bodily forward; the semi-fluid silt flowing around the tube as it progressed. Great care was required where the tube passed out of the sand or silt into rock which required drilling or blasting. At such places, the river-bed was covered with a layer of clay to enable the air-pressure to be adequately maintained without causing a blow-out between the soft and the hard material. In one of the subway-tunnels, a man was blown through thirty feet of ooze and water into the open air, yet he escaped unhurt. The ordinary maximum pressure was 36 pounds per square inch; though in joining the tubes, as the ends met, the pressure was temporarily increased to 51 pounds. In the subway-tunnels, the air-lock was not used. The shield was driven forward by seventeen hydraulic jacks, each exerting a thrust of 350,000 pounds, and by their relative pressure the tube was kept in alignment under the varying conditions of external resistance. Under 22 pounds' pressure, the men worked seven and a half hours in an eight-hour shift with a half-hour interval; under 35 pounds, they worked in two shifts of two hours each with a four-hour interval; under 45 pounds, they worked but one hour and twenty-five minutes in eight hours.

[1] Details as to tunnel construction in and around New York City are given in Appendix IV, Table VII.

The Pennsylvania Railroad Tunnels

All previous subaqueous tunnel-work was dwarfed in the construction of the Pennsylvania Railroad tunnels under the Hudson and the East rivers. The bed of the Hudson River is of silt, so loosely compacted that it would have been impracticable to drive a tunnel through it in open air. The main level of the tunnels is therefore kept at a great depth, so that the weight of the superincumbent material may be sufficient to resist the necessary air-pressure. Indeed, the silt is of such a light consistence that much of the advance was accomplished by pressing against it with such force that it exuded through the openings in the shield.

The twin-tubes of the Pennsylvania Railroad tunnels are built of cast-iron rings, 2½ feet long and 23 feet in diameter, each composed of eleven segments and a key, and of a total weight of 11½ tons. They are lined with concrete, leaving 18 feet clear internal diameter. A concrete walk, 6 feet in width, extends along each side of the tube at the height of the car-windows, in which are imbedded the conduits for the water-pipes, the power-cables and the signal-wires. As there is but six inches' clearance above the car-roof, ventilation is assured merely by the trains forcing the air ahead of them and the fresh air following. When the faces of the Hudson River tubes, 6000 feet in total length, had approached within 125 feet of each other, the alignment was tested by connecting the parallel tubes on each side with six-inch pipes, through which instrumental observations were taken. It was found that the tubes were out of alignment one-eighth of an inch horizontally and three-fourths of an inch vertically.

The Sunken Tube Method

Another plan for the construction of subaqueous tunnels has been successfully applied under suitable conditions. In 1845, De la Haye, of England, suggested making a submarine railway by constructing wrought-iron tubes above water in sections 400 feet long, bulkheading them so that they would float, towing them to the tunnel-location, then admitting water and sinking them to a suitable bed. M. Belgrande, in 1866, built a pair of sewer-tunnels on this plan under the Seine at Paris. Each had a diameter of one meter, was 156 meters long and was made of iron plates. The first masonry-tunnel on this plan was constructed in 1893–1894 by Mr. H. A. Carson, in the outer portion of Boston Harbor, for the Metropolitan Sewer. The sections of 50 feet in length were made of a combination of brick and concrete, with exterior wooden staves, four inches thick. Their external diameter was a little more than nine feet, with external flanges for bolting contiguous sections. Temporary bulkheads were inserted and were tested for tightness by exhausting the air and measuring the rarefaction by a vacuum gauge. They were made in cradles above the water, were lowered by vertical screws and towed to their positions, filled with water and lowered to saddles sunk in trenches dredged in the harbor-bottom. The sections were bolted together by divers with rubber gaskets between the flanges. The trenches were filled in, the bulkheads removed and the water pumped out. The spaces which the bulkheads had occupied were then closed with masonry. The whole tunnel, 1500 feet in length, was water-tight, true to line and level, and satisfactory in every way.[1]

The Detroit River Tunnel

The most important subaqueous railway tunnel in America, outside of New York City, is that under the Detroit River, built by a combination of the railroad companies interested in the international traffic between Detroit and Windsor. The Detroit approach of 3669 feet includes an open cut of 1510 feet; the subaqueous portion is 2668 feet and the Windsor approach is 6449 feet, including an open cut of 2900 feet. The total length of the line as constructed is, therefore, about 2.42 miles. The tunnel consists of two single-track tubes with a maximum gradient of 1.5 per cent. on the Windsor approach and of 2 per cent. on the Detroit approach and a maximum curvature of two degrees. The entire excavation was in blue clay. On the Detroit side, it was found necessary to use compressed air for 450 feet from the river, and for nearly all the way on the Windsor side. The approaches are in plain concrete, except for some longitudinal rods in the inverts. In Windsor, the clay came in at the working-face about as fast as it could be removed, and excavation for the dividing-wall between the tubes was carried on for about 2000 feet with a shield above the bottom-drift. As the subaqueous section was approached, the movement of the shield became so erratic that it was abandoned, and the remainder of the wall was built in headings under compressed air. The work was then completed with "side-shields," semi-elliptical in shape. These shields extended from over the springing of the arch in the center-wall around the bottom of the invert, including a ring of timbering, 10 inches thick, outside of the concrete. The outside shell was of $\frac{3}{4}$-inch steel, reinforced with angle-iron. The main body was $7\frac{1}{2}$ feet long, with a heavily reinforced cutting edge. It was divided on the working-face for six pockets, through which the clay was excavated and deposited on a tail-piece of $\frac{1}{2}$-inch steel, until the timbering was placed. Each shield was supplied with twenty-one 5-inch hydraulic jacks, with 20 inches extension, worked up to 8000 pounds per square inch. Later, the two bottom-jacks were replaced by 8-inch jacks, and another 5-inch jack was added next to the central wall on top.

The clay was cut with semi-circular knives, pulled by two men and guided by a third. By means of a conveyor, operated by compressed air, the

[1] H. A. Carson, "Discussion on the Detroit River Tunnel." Trans. Am. Soc. C. E., December 1911.

excavated material was loaded upon narrow-gauge cars standing on a track carried by a working-platform behind the shield. These cars were cable-hauled to the shaft, elevated to the surface and dumped on flat cars. The excavation was carried about two feet ahead of the shields. As the shields traveled along the central wall, there was little trouble in keeping them in line, but it was more difficult to keep them to grade, than if they had been of a full section with jacks on all sides. In the drifts, the usual rate of progress was about twelve feet in twenty-four hours, and with the side-shields about ten feet. Compressed air was used as required. The Detroit approach was built in the same way.

The water-proofing in the approach-tunnels was made of alternate layers of felt and coal-tar pitch, varying in thickness from seven to twenty-two layers. The concrete was laid in runs of twelve feet and each run was allowed to set sufficiently for the form to be moved before the succeeding run was made. The concrete for the center-wall was deposited from the surface through chute-holes, except for the work under compressed air, where the top-drift was made high enough for the concrete for the entire wall to be delivered in cars.

The subaqueous portion of the tunnel is 2668 feet in length and is level for about 1000 feet, but both ends are on curves. The method of construction was entirely new, as applied to subaqueous tunnels. The plan consisted in dredging a trench of the required width and depth, sinking to correct position water-tight steel tubes and surrounding them with concrete deposited in the water. Before the tubes were unwatered, the trench was back-filled with clay to the full height of the exterior concrete deposit. By means of two water-tight openings, the concrete-lining was built in the atmosphere.

The tubes are 23 feet 4 inches in diameter, of $\frac{3}{8}$-inch plates, sunk in pairs, 26 feet 4 inches between centers. The sections were 262 feet 6 inches long, except one of 238 feet 6 inches and the closing section of 64 feet 6 inches. The tubes were reinforced by circumferential stiffener angles, 4 inches by 3 inches and $\frac{3}{8}$ inch thick, riveted to the inside at intervals of 12 feet. They were further stiffened for sinking by 12 steel rods, $\frac{7}{8}$ inch square, radiating from a cast-steel ring in the center of the tube, and bolted to the stiffener angles. For depositing the exterior concrete, the tubes were surrounded with steel diaphragms at intervals of twelve feet, to the ends of which was attached wooden sheathing, six inches thick at the bottom, diminishing to three inches at the top. Each pocket thus formed could be filled from top to bottom, independently of the adjacent pockets, with concrete of a minimum thickness of three feet. The bottom of the diaphragms was made straight to give a level bearing.

The bottom of the trench was from 60 to 80 feet below the mean water surface. The average depth of the river-bed is 36 feet, with a minimum depth of 18 feet, and a maximum of 48 feet. For a distance of several hundred feet in the middle of the river, the top of the tunnel is from three to seven feet above the river-bed, with a depth of 41 feet in the main channel. It was found that a dipper-dredge could not be used on account of the strain upon the anchoring-spuds, and the dredging was done with a clam-shell bucket of three cubic yards' capacity. The average performance was 600 yards of clay per 10 hours, with a maximum of 1400 yards per day and of 25,000 yards in one month, place-measurement. Care was taken not to waste clay from Canadian waters across the international boundary, in order to prevent the imposition of United States customs' duty. The depth and width of the trench was ascertained by sweeping it with a 24-inch "I"-beam, 48 feet long, suspended from a derrick scow. At the points for joining the tube sections, a grillage of "I"-beams was placed at the proper level upon a deposit of concrete, by lowering it from derricks on the scow which carried the apparatus for sinking the tubes. The grade was determined by a steel mast, 80 feet long, which served as a level rod, and was also suspended by a derrick.

The ends of the tubes were fitted with bulkheads, four inches thick. In each was a 14-inch gate-valve just below the line of flotation and, at the top, a 2-inch air-escape valve with hose reaching above the surface, after the section had been sunk to its position. There were two semi-bulkheads in each tube, 9 feet deep and 48 feet from the end-bulkheads. These bulkheads formed an air-chamber at each end, by which the section was kept on an even keel, by controlling the sinking through the air-escape valves. As the section sank, the air from the middle of the tubes escaped through a 4-inch pipe back of each bulkhead. The openings for these pipes were capped by divers afterward. The time required for submergence of a section was about two hours.

Four air-cylinders were used for floating the sections, two over each tube and connected to the diaphragms. Each cylinder was 10 feet 2 inches in diameter and 60 feet long, divided into three compartments, fitted with water-valves and air-escapes. These compartments were so proportioned that, with the end ones empty, and the tubes filled with water and completely submerged, about 18 inches of the top of the section was above the surface. The middle compartment was then filled and the section was lowered into position. The submergence was more accurately controlled by two 5-ton counterweights suspended from derricks on scows alongside, by which additional load could be imposed as required, and the section could be raised or lowered a fraction of an inch by regulating the water in the air-cylinders. After the section was in position and sufficiently anchored by concrete, the air-cylinders were detached by divers and used for the next section. The total weight as submerged was 550 tons of metal, 240 tons of wooden material and 110 tons of air-cylinders: 900 tons in all, weighing 516 tons when entirely submerged. The section was held in position against a maximum current of 3½ miles an hour by concrete anchors weighing 22 tons each, under water, and buried 700 feet up-stream. The sinking apparatus was carried on a derrick-scow, 35 by 120 feet.

The sections were connected by a joint consisting of a "pilot-pin" 6 feet long and 6 inches in diameter, fitting into a socket in the end of the preceding section. The end of the pin was slotted to receive a key which, when driven home, secured the end of the section in position. An annular pocket, 4 inches deep and 8 inches long, was made water-tight by rubber-gaskets and, after the tubes were unwatered, this pocket was filled from inside with grout. The connection was further strengthened by bolts outside, placed by divers. The position of the section as to line and grade was determined by steel masts, one on each tube at the east end and one on the west-bound tube at the west end. Each face of the masts was marked with a center-line and graduated in feet, referring to the center of the tube. The grillages were set several inches below the bottom-grade of the diaphragms, and the level accurately secured by shims placed by divers. When a section was finally deposited, it was anchored to the grillage by a turnbuckle. The total time consumed in sinking a section and in making ready for the concrete was from three to seven days.

The concrete-mixers were carried on a scow, 36 by 155 feet, fitted with spuds 20 by 20 inches and 90 feet long. On one side of the scow there were three tremie-pipes, 26 feet 4 inches between centers and extending 89 feet above the water. The pipes were in 16-foot lengths, 12 inches in diameter. When a section of tubes was in place, the tremie-pipes were lowered into one of the pockets formed by the diaphragms, to within a foot of the bottom of the trench, with the middle pipe between the tubes and the others outside. The lower ends of the pipes were usually held from three to five feet in the concrete and the flow regulated so that the pipes were kept filled with concrete during the run. The placing of the concrete was inspected by a diver, who saw that it was carried to about six inches above the top of the diaphragms, and this was verified by soundings. There was a hydrostatic pressure of about 30 pounds per square inch at the bottom of the tubes. The total quantity of concrete, 101,900 cubic yards, was placed in a working-period of 18 months. The maximum quantity placed in a day of 16 hours was 1069 cubic yards, and the maximum for any one month was 10,287 cubic yards. For the back-filling, gravel was used to a height of eleven feet above the foundation concrete. The remainder was filled with clay, as excavated by the dredgers, and then covered with riprap to the depth of two feet.

For unwatering the tubes, the west end of the westernmost section and the east end of the other alternate sections had been fitted with bulkheads of 10-inch by 12-inch yellow-pine timber, heavily braced to withstand the hydrostatic pressure, with a 10-inch valve for unwatering in each bulkhead. An opening was connected through every two alternate sections by means of the 14-inch inlet-valves used in filling the tubes. An access-pipe, 4 feet in diameter and extending above the surface when the section was in place, had been provided at the west end of each tube in the first section, as also a 12-inch discharge-pipe. Centrifugal pumps were placed under these pipes and the pump-shafts led up through them. For carrying water to the pumps, a 12-inch pipe had been laid through each of the first five sections in advance of the sinking. After the first section had been unwatered, the remaining sections were unwatered in pairs. When the sections were all unwatered, they were found to be watertight.

The concrete-lining of the full section, except over the access-pipes, was placed in four runs; viz.: the invert to 12 inches below the bench-wall; the two side-walls to 8 feet above the bench, and finally the arch. The concrete was mixed on the surface at the Detroit end and delivered through chutes in the access-pipes upon a platform suspended at the level of the top of the side-walls, and advanced with the progress of the work, the narrow-gauge track being shifted from the platform to the completed invert. The cars were drawn by cable and thirty minutes was the longest time required to deliver the concrete to the Windsor connection; a distance of more than 2700 feet. Steel forms were used for the lining, 24 feet long for the inverts and 12 feet for the arch. The lining was completed in exactly twelve months.

The connection between the subaqueous tunnel and the western approach was made in the dry, in a coffer-dam. At the eastern approach, the end of the approach-tunnel had been covered by a steel plate, which served as a water-tight surface against which the tubes abutted. To prevent an inrush of water into the approach-tunnel, three concrete bulkheads with steel doors had been built into the work, 50 feet apart. The closing section, No. 11, was 64 feet 6 inches long, and the gap to the next full-section was 65 feet 4 inches, when No. 11 had been placed against the end of the approach tunnel. The interval of ten inches between the last two sections was closed by divers with a joint of special design. The closure was sealed with concrete when the tubes were unwatered, and covered by a plate bolted to the tubes. The difference in level through the completed tunnel was $\frac{1}{10}$ of a foot.

The contract for the tunnel was awarded August 1, 1906. The work was commenced October 1, 1906, and completed July 1, 1910. The tunnel was opened for all traffic in October, 1910. It has overhead clearance of 18 feet to the top of the semi-circular arch, which has a radius of 10 feet. The top of the bench-walls is 5 feet 3 inches above the rails and the distance between them is 11 feet 6 inches. Safety-ladders, staggered in 25-foot intervals, are built into the bench-walls. The tunnel is lighted by 16-candle-power 110-volt incandescent lamps, staggered every 20 feet, with two separate circuits. Conduits for telegraph, telephone, power and signal circuits are built into the walls, also splicing-chambers every 400 feet. All water is drained into five sumps; one at each portal, one in each approach near the river, and one under the middle of the river, with capacity of 30,000 to 40,000 gallons. Each sump is provided with a pump and electric motor. Under the center of each track is a gutter, 6 inches deep in the approaches and 10 inches in the subaqueous tunnel. The tunnel is provided throughout with a 6-inch water-line, and hydrants and alarm-boxes every 100 feet. As the tunnel is operated electrically, there is no special system of ventilation.

The track is of special construction. Each rail, of 100-pound section, rests on ties 8 by 11 inches and 3 feet long, except every fifth tie, which is longer to receive the third-rail on the right-hand side in the direction of the traffic. The inner ends of the ties are at the edge of the gutter. The ties are held in place by concrete to a depth of 5 inches at their outer ends, with one-inch slope to the gutter.

The line is operated with purchased current, three-phase, 60 cycle, 4400 volts, converted at a substation costing $260,000. The third-rail is of the under-running type, 70-pound section, and of a total length of 18½ miles; though the third-rail section is only about 4.4 miles. The signaling is arranged to make one block between the portals and the interlocking plants in each terminal yard operated electrically. The yards are lighted by arc series-lamps.

The location of the approaches destroyed two terminal yards in Detroit and one in Windsor. The latter was readily removed to a more convenient location. In Detroit, it was necessary to reach the main switching yards, three miles west of the tunnel. This required the crossing of some thirteen streets by separating the grades and, within the limits of 2½ miles, there were over thirty industrial tracks. A union passenger-station was also built in connection with the tunnel.[1]

The construction of the Detroit River tunnel is remarkable for the ingenuity of the method devised for the construction of the subaqueous portion, for the thoroughness with which the details were prepared, for the rapid progress of the work and its successful completion without serious accidents. It was estimated that by this method of construction, $2,000,000 had been saved, with the advantage of building the tunnel on a level fifteen feet higher than would have been practicable with compressed air, and a corresponding saving of 1750 feet of length in the approach-tunnels.

The sunken-tube method of construction was employed in carrying the Lexington Avenue Subway under the Harlem River through a tunnel on which work was commenced in 1914. This tunnel is in four tubes, each 19 feet internal diameter, incased in quadruple sections 200 feet in length. Here the descent was regulated by the admission of compressed

[1] "The Detroit River Tunnel," W. S. Kinnear. Trans. Am. Soc. C. E., December, 1911.

air into chambers at the ends. The buoyancy of the sections was overcome by loading them on top as they sank between guide-piles to their position in 20 to 26 feet of water; the top of the tunnel being 28 feet below high water.

In all these cases of subaqueous tunnels, the depth below the water line is so much less than the necessary height above it for bridge clearance that the resulting gradient is considerably easier. The expensive construction of piers is avoided and their obstruction to navigation; as also the occupation of valuable riparian property for approaches.

Railway Underground Approaches and Subway Systems in Large Cities

The difficulties encountered in the entrance of railways into populous cities have been overcome by expensive construction and by engineering skill. The preservation of a terminal station in the heart of a great city could only be secured by elevating the approaches to it upon viaducts, through which the streets are passed, as with the London & Blackwall Railway. The exigencies of city traffic were partially relieved in Berlin by the Stadtbahn, opened in 1878. This is a four-track line of twenty miles; twelve miles of it costing $18,000,000. It is carried across the city for the most part on embankments and masonry-arches. An elevated railway of the same kind was built in Liverpool in 1894. But the traffic along the streets could not be conducted by railway lines on masonry, and recourse was had to iron viaducts spanning the roadway. An extensive system of this character was developed in Chicago beginning about 1880, and another in Boston twenty years later. Structures of this character have cost from $300,000 to $400,000 per mile, exclusive of equipment, terminals and land-damages. Though the iron viaduct was preferable as a substitute for the surface-railway as a means of rapid communication, the piers are a serious obstruction to street-traffic, and the nuisances caused by passing trains to the occupants of adjacent buildings were but little diminished by the introduction of electric traction.

With the improvement in underground construction, relief was sought by placing the railway lines beneath the streets instead of above them; a change of level that was invited where rivers intervened in the approaches. These "subways" may be said to have originated in Paris in the construction of passage-ways beneath the streets for sewers and for pipe lines.[1] Now, the underground mileage of urban and suburban lines, constructed to meet social requirements, far exceeds the railway-tunnel mileage rendered necessary by topographical conditions.

[1] In 1843, a subway was built beneath Atlantic Avenue, Brooklyn, as an approach by the Long Island Railroad to its former terminus at South Ferry, but was afterward filled in. It was a double-track tunnel, 21 feet wide and 17 feet high. George T. Hammond, "Discussion on Railway Development." Trans. Am. Soc. C. E., December, 1911.

The introduction of railways into cities by subways was undertaken on a grand scale to expedite the suburban traffic with the metropolis of London by the construction of the Metropolitan Railway, which was opened in successive sections in 1863, 1865, 1868, 1871 and 1876. The circle around the city was completed in October, 1884, by the construction of the District Railway. The total route-mileage of 101.8 miles was built at a cost of $132,000,000, and was operated by steam, until electric traction was introduced in 1905. The internal section was made with a width of 28½ feet to accommodate trains of the Great Western Railway, which was then of a gauge of 7 feet ¾ inch. The line was kept so close beneath the surface that the platforms were reached by stairways at a minimum of 18 feet from the street. The work was carried on by "cut and cover." The trench was excavated in the open and was filled in after the masonry was built. Where the line was very near the surface, the space was bridged with heavy girders with jack-arches between them to carry the pavement. The tunnel, which is elliptical in cross-section, was built without inverts, and it became necessary to introduce concrete struts between the walls and beneath the tracks to resist the external pressure.

The more recent subways in London have been constructed in tubes, with a total mileage of 35 miles and at a total cost of $105,000,000. The tracks are usually in single tubes from 10¼ to 16 feet in diameter internally, enlarged at the stations. Though for the most part driven with excavating shields, compressed air was but seldom used. They were built on a much lower level than the Metropolitan Railway, to avoid the maze of underground conduits, to diminish danger to the foundations of adjacent buildings, and, in some instances, to pass one tube under another.[1] Access from the street is usually had by elevators or lifts, at depths of 100 to 190 feet, accommodating from 60 to 75 persons, and limited to a maximum speed of 200 feet per minute. Moving stairways have also been tested experimentally.[2]

In 1893, a subway for electric traction was constructed in Buda-Pest, Hungary, by "cut and cover," with the rail-level but nine feet beneath the surface of the street, which was carried on steel beams close together with jack-arches between them, and a total thickness of only twenty inches. The entrances to the stations are through "kiosks" at the street corners. With the exception of the Untergrundbahn, now under con-

[1] In the construction of the Glasgow Central Railway 7¼ miles in length and opened in May, 1890, it was necessary to provide underpinning on each side of Argyle Street for two miles. Sheet-piling, 12 by 6 inches, was driven to a depth of 25 to 30 feet from an overhead traveling stage, moving on wheels at the street-level.

[2] Most of the information as to tunnel-work in Great Britain has been obtained from a paper by Francis Fox, Mem. Inst. C. E., published in the Proceedings of the International Railway Congress in Berne, in 1910, from which have also been compiled the statistics as to London subways in Appendix IV, Table VI.

struction in Berlin, the only other subways of importance in the cities of continental Europe are in Paris. The Metropolitan Railway, with about 50 miles of line, begun in 1898, is for the most part underground and is carried under the arms of the Seine for distances respectively of 306 feet and of 132 feet by tunnels driven with compressed-air caissons. The new terminal station of the Paris & Orleans Railway, at the Quai d'Orsay, is also approached through a subway along the bank of the Seine.

The subways for the street-railways in Boston and in Philadelphia have been constructed by "cut and cover," with the exception of the Boston subway to East Boston through a subaqueous tunnel.[1] The separation of the railway and street traffic in and around Chicago has been prosecuted since 1892 in a complication of steam and trolley lines that is unparalleled elsewhere, as it includes either the elevation or depression of 838 miles of steam-railroad tracks. Chicago has also a unique system of subways for freight-traffic only, underlying its business-district, and connecting the basements of important business-houses with all the freight-terminals. The tunnels of concrete, with cross-sections of 12¾ feet by 16 feet and 7½ feet by 6 feet, are driven through firm clay. In 1905, there were 65 miles of this subway, operated by trolley-motors on a two-foot gauge.

Elevated Railways and Subways in New York City

Subway systems have been developed in and around New York City which, as to cost, extent and engineering difficulties, are of a magnitude that has commanded attention and admiration throughout the world. The character of the work has been diversified by reason of the geographical position of Manhattan Island, isolated by broad rivers from the populous shores of New Jersey and of Long Island, and by the configuration of the island itself, which has restricted the local lines of communication within a long and narrow space. Its area is closely covered with buildings, many of whose foundations are based on a soil saturated with subterranean waters, and others with basements two to three stories beneath the surface, extended as vaults under the sidewalks. Beneath the pavement between these vaults, there is a maze of sewers, of gas and water mains, and of conduits for electric cables, uncharted and many of them in a precarious state of disrepair.

An effort to relieve the streets of their congested traffic was attempted in 1868 by A. E. Beach, editor of the *Scientific American* and inventor of the plan for pressing tunnel-shields forward by hydraulic rams.[2] He obtained a charter for a conduit under Broadway for the transmission of parcels by pneumatic propulsion. In 1873, the project was amended to undertake the construction of a subterranean railroad from the Battery to Harlem River. The work was commenced near the Astor House, and a section of the tunnel had been completed, when it was interrupted by

[1] See p. 199. [2] See p. 195.

litigation that effected its abandonment. In February, 1912, it was found to be still in good condition.

In 1870, a street-railway was built in New York City, with a track supported by a row of iron columns along each curb. This was replaced in 1878–1879 by a more substantial structure spanning the carriage-way and capable of carrying four tracks. From this beginning, have been developed the extensive systems of elevated railways in New York and Brooklyn.

The first important underground railway work in New York City carried the New York Central line beneath the street-crossings to Forty-second Street. It has been recently rebuilt on a far more extensive scale in connection with the construction of the new Grand Central Station. In its present form, the approach is so completely underground with structural supports of immense strength that the surface has been made available for building-sites of great value.

The Pennsylvania Railroad line has also been brought into its new terminal station in New York City by a subway-approach from the Hudson River tunnel and extended to the East River tunnels through Thirty-second and Thirty-third streets in subways 42 feet wide and 21 feet high; the tracks being separated by a dividing-wall. Beyond the eastern tunnel-portal, the line of the Long Island Railroad is continued for some miles by either elevating or depressing its tracks, with a further extension to the Port Morris terminal of the New Haven line, by bridging the three outlets of East River into Long Island Sound.[1] The subway in connection with the Hudson & Manhattan tunnel has already been mentioned in this chapter.

The municipal subways in New York City had their inception in the organization of the Rapid Transit Commission to facilitate passenger-travel within the city-limits. Work on the original Rapid Transit System was commenced March 25, 1900, and the line was opened to Broadway and 145th Street, October 27, 1904. The 20.47 miles of track, including the Lenox Avenue Branch, of which five miles is on viaducts, cost $40,000,000. The extension under East River into Brooklyn was opened January 9, 1908. The system was completed with the extension to Van Cortlandt Park, when its line of 20 miles from end to end had cost $60,000,000. A subway was next built as a loop between the Brooklyn and the Williamsburg bridges, and then followed the project for the second system. The entire system of the dual subway, when completed, will comprise 629 miles of tracks at an estimated cost of $507,000,000. Taking all these public works together, including the East River bridges, the investment within and immediately around New York City for facilitating personal intercommunication only, by elevated and underground railways, may be estimated at not less than $1,000,000,000. In addition, a

[1] See Appendix IV, Table VIII.

plan is now about matured for removing the freight-tracks of the New York Central Railroad from the streets on the West Side by a line beneath Riverside Park and a viaduct through the blocks for the remainder of the route to the freight-terminal in St. John's Park.[1]

The subway system of New York City has a cross-section of 26 feet 3 inches wide by 13 feet above the rail. In the original form of construction a metal-lining of steel stanchions was placed every five feet against a concrete wall, filled in with an invert of 20 inches of concrete. The roof of concrete jack-arches between the cross-girders was 31½ inches between the tunnel and the surface, further supported by iron columns between the tracks. Subsequently, this plan was changed to one wholly of reinforced concrete, in which the thickness of the roof was increased to 5 feet 3 inches between the middle row of columns. The Pennsylvania Railroad double-track subway, on the Hudson River side of the terminal station, was built with a full arch, concrete side-walls and brick vaulting. On the East River side, there are two double-track tunnels, each with a brick arch resting on side-walls.

Special Features and Ventilation

The underground work in New York City has been prosecuted through unstable soil and through solid rock, under every conceivable difficulty from subterranean waters, from obstruction by existing subways, sewers, water-mains and cable-conduits, and in the protection of the foundations of adjacent buildings. All approved methods and appliances have been skillfully utilized; many of them have been greatly improved, and, with added experience, others have been developed which are remarkable for the ingenuity displayed in devising them.

Tube-construction has been but rarely resorted to. On account of the weight and dimensions of the excavating shield, it is moved and guided with difficulty, and it can not be accommodated to varying cross-sections. If the shield is at all near the surface, the pressure which it exerts may raise the pavement at times as much as two to three feet in height. The usual method has therefore been that of "cut and cover," opened at night and covered by day. In later construction, the streets are supported by timber and planking, permitting continuous work beneath. In Forty-second Street, where the rails are 36 feet below the surface, a trench was opened only to the width of one track, and the wings for the other three were cleared out by cross-drives; the roadway above being supported by beams and girders as the work progressed.

In Europe, wherever arched masonry could be used, it has been found less expensive than a metal roof, though the latter has the advantage of bringing the stations nearer the surface. Reinforced concrete has been more generally used for subway-construction in the United States. In

[1] Further information on this subject is given in Appendix IV, Table VII.

underpinning the foundations of adjacent buildings, it is unadvisable to place reliance on iron girders as permanent supports. There have been instances where the web of a girder, originally an inch thick, had been found reduced by corrosion to the thickness of a sheet of writing-paper. The movement of materials in crowded streets is often such an obstruction to the normal traffic as to warrant considerable expense in devising ways of transport; as where the bank of a river or canal, or a railroad-track, might be reached within a reasonable distance by cross-drives.

Where subway-lines are operated by electric traction, no provision has to be made for the removal of gases from coal-combustion. The Metropolitan Railway in London was notorious for bad ventilation before it was electrically operated. The proportion of noxious gases, amounting to from 60 to 89 parts per 1000, was then reduced to a maximum of 11 to 14 parts. Artificial ventilation has, however, been applied in the electrically operated "tubes." Since 1902, the Central London Railway, six miles in length, has been ventilated by an exhaust-fan of 5 feet face and 20 feet in diameter at one end of the line, driven by 300 horse-power. Several times during the night, the doors of the intermediate stations are closed and the line is swept from the other end by a current of fresh air, by which the proportion of noxious gases is reduced to 7 parts per 1000; the outside air at the same time containing 4.4 parts. In some of the later tubes, electrically-operated fans are placed at half-mile intervals; each exhausting 18,500 cubic feet of air per minute. In the Boston subway, the air is completely changed by exhaust-fans every fifteen minutes. The air in the Pennsylvania Railroad subways in New York is changed automatically by the passage of the trains, but in the subaqueous tunnels there is an emergency provision of exhaust-fans. In the Rapid Transit subways, reliance is placed upon natural ventilation, though not altogether with satisfactory results. The ventilation is effected through openings in the walls of adjacent areas under the sidewalks. These openings are 60 feet in length by 5 feet in width, covered by gratings for foot-support and to prevent the entrance of rubbish into the subway.

Proposed Tunnel under the English Channel

A discussion of railway tunnel-work may well conclude with some reference to the projected tunnel under the Channel between England and France. Such a tunnel for a carriage-way was proposed to Napoleon Bonaparte, in 1802, by a French engineer. Thomé de Gamond, another engineer, prepared five separate plans for a railway tunnel, between 1834 and 1856. One of these was reconsidered by I. K. Brunel, Robert Stephenson and Joseph Locke, and was the subject of an exhibit at the Paris Universal Exposition in 1867. In 1869, Thomé de Gamond obtained the support of an Anglo-French committee for the incorporation of a company to obtain a concession for carrying his plan into effect. Then the diplomatists intervened and it was not until 1874 that the British government authorized a joint commission to prepare an agreement under which the work might be undertaken. In 1876, the commission presented its report for ratification by the legislatures of the two countries.

In 1875, the French government had already sanctioned the formation of a Channel Tunnel Company, granting it a concession for the railway connection in France, for a period of 99 years from the date at which the tunnel should be opened for traffic. In England, three companies, that had separately occupied themselves with the matter, were merged in 1886 into the Submarine Railway Company, which began work by driving a heading for 1¼ miles, of which a mile was under the sea, when public opinion was aroused against the project, through the press and by petitions to the government. Military and naval experts expressed alarm at the possibility of invasion by way of such a tunnel, and the attempt to obtain parliamentary sanction was withdrawn. Similar attempts in 1887 and in 1906 were equally unsuccessful, but a favorable change in public opinion is expected upon the termination of the present European War. Recent improvement in the methods and appliances for subaqueous tunnel-construction have rendered the project more feasible than heretofore.

From geological examinations, trial borings and soundings, valuable information has been obtained as to the formation of the bottom of the sea and as to the composition and stratification of the underlying material. In addition to the heading driven from the English shore, one has been driven from the French coast for an equal distance under the sea. From this experience, it has been ascertained that a continuous stratum of cretaceous rock underlies the Channel and extends under both shores, which is sufficiently compact and impermeable to admit of driving a tunnel through it without lining.

The plan now recommended is for two parallel tunnels 50 feet apart, circular in cross-section and connected by cross-drives every hundred yards, with an independent drainage-tunnel. As the drainage-tunnel progresses from each shore, the main tunnel would be driven from it at from four to seven different places. The gradient would not exceed 20 feet per 1000, and at the lowest point the tunnel would be 328 feet below sea-level and 164 feet beneath the bed of the Channel. A system of ventilation has been devised for supplying fresh air to the work during construction and for exhausting vitiated air when in operation by electric traction.

On the French side, the line would diverge from the Northern Railway between Boulogne and Calais to Wissant on the coast, and thence descend to the sea by a loop-line over a viaduct half a mile in length and 46 feet high, in order to meet military objections raised in England, and to permit of the destruction of the viaduct by a British fleet. On the English side, the entrance to the tunnel would be at the back of Shakespeare's Cliff, west of Dover, under direct fire from three forts. It is estimated that the work can be executed within a period of seven years and at a cost of $80,000,000. The whole length of the tunnel would be 33.6 miles and the total time for express-train service between London and Paris would be about five hours, or two hours less than under present normal conditions.[1]

[1] For additional information, see Proceedings of International Railway Congress, Berne, 1910. Vol. I, Part IV, p. 61.

CHAPTER V (*Continued*)

PART II. SUPERSTRUCTURE

Development of Track. — The Edge-rail. Wheel Flanges. Bull-head Rail

The substructure of a railway is in many respects much like that of other highways, except as required by a different mode of traction, involving heavier loads and higher speeds. It is only because of its superstructure that the railway becomes no longer a public highway, open to all comers. In its inception in England, the railway track was merely an improved surface of the ordinary road, enabling it to bear up better under heavy traffic from the collieries. With this purpose in view, in 1633, broad beams were laid longitudinally at bad places in the roads.

From this beginning was developed the "stringer track," of pieces of oak or fir, about six feet in length, four to six inches wide and four to five inches thick, pegged down to sleepers placed about two feet apart, so that each stringer was supported by three sleepers. This form of track was next improved by an arrangement known as the "double-way," in which a rail of beech was laid on top of the oaken stringer and took the wear. The space between the rails was filled with cinders or broken stone to protect the feet of the horses from the sleepers. Then at the curves, or on steep grades, there were laid strips of iron, known as "plates," two inches wide and half an inch thick. About 1738, this practice was extended until the "tramway" or "dramway" generally supplanted the double-way.[1]

About 1767, cast-iron plates were substituted and, in 1776, to strengthen these plates as well as to guide the wheels, they were cast with a flange from two to three inches high. Such plates were six feet in length, three inches broad, half an inch thick and from 47 to 50 pounds in weight. The under-rail was no longer used; the plates were spiked directly to the sleepers. This form of track was known as a "plate-way," and to this day, in England, track-hands are termed "plate-layers." Where these plate-ways crossed a turnpike, the raised flange was very objectionable. In 1788, William Jessop, who was building a plate-way, conceived the idea of transferring the flange to the wheels and turning the plates on edge as "edge-rails"; and the "railway" was born.

[1] The first section of the Great Western Railway, opened in 1838, was stringer-track with a heavy rail.

These edge-rails were cast in three-foot lengths, fish-bellied and with top and bottom flanges. The lower flange, at one end, was spread out as a foot and spiked directly to the sleeper, and a socket in this end received the plain end of the adjacent rail. As the spread-end was found to break in service, Jessop, in 1797, invented a cast-iron "chair," in which the ends of the rails were inserted.

In 1805, the edge-rail was rolled in wrought-iron in lengths of twelve feet and of a section 1½-inch square, supported on stone blocks at intervals of three feet; but the cast-iron rail was not superseded until 1820, when Birkenshaw had patented an edge-rail with a "T" head. This rail was rolled in lengths of 15 feet, of a section 1¾ inches wide at top, weighing 25 pounds per yard; with a channel or groove on one side of the lower part of the stem, by which it was secured to the chairs with wooden keys.[1] Later, these rails were rolled in a fish-bellied pattern with a head 2¼ inches wide, fastened to the chairs with pins or bolts. Such rails were laid on the Stockton & Darlington Railway in 1822–1825.

In 1829–1833, George Stephenson used a pattern weighing 35 pounds per yard, 2½ inches deep at the chairs and fish-bellied between them to 3½ inches. A projection on one side of the end of the stem fitted into an opening in the chair, and an iron key on the opposite side held the rail in position. Difficulties in rolling this rail led to the abandonment of the fish-bellied pattern, and attention was directed to the "parallel rail" rolled in 1834, with a knob at the foot of the stem and weighing 42 pounds per yard. From this section was developed the "bull-head" pattern, rolled in lengths of 15 feet and weighing 68 pounds per yard, secured in the chairs by wooden keys.

In the meantime, in 1835, the "double-head" pattern was introduced to be turned bottom upward after the upper surface had become worn. A section of this pattern was rolled in 1838, weighing 78 pounds per yard; the additional weight being intended to reduce the cost of chairs and sleepers by placing them five feet apart. After an experience of some thirty years, it was found that the bottom surface was so much worn in the chairs that the rail could not be turned to advantage, and the bull-head rail became the standard pattern in Great Britain. In 1875, such rails were rolled in 24-foot lengths weighing 83 pounds per yard; in 1893, in 30-foot lengths weighing 85 pounds; in 1896, in 36-foot lengths, weighing 100 pounds, and subsequently in lengths of 45 feet.[2]

[1] The Liverpool & Manchester Railway was laid with edge-rails of forged iron, in lengths of 15 feet, weighing 35 pounds per yard and supported every three feet on stone blocks.

[2] For further information as to the genesis of the railway track in Great Britain, see "History of Inland Transport and Communication in England," E. A. Pratt, London, 1912; and "Modern British Permanent Way," C. J. Allen, London, 1915.

Early American Structures. Strap-rails and T-rails

Railroad transportation was introduced into the United States at a time when labor was as difficult to obtain as was capital. Early operation was all-important, and cheap construction of more immediate benefit than easy grades and curves. There were but few auxiliary ways for the delivery of materials from any considerable distance; so that the best use had to be made of those which were at hand. Therefore, the road-bed was ballasted with sand, the cuts and fills were left unsodded and exposed to wastage by weather. The bridges were often built by house-carpenters with timber cut from adjacent forests and wrought into beams with the pitsaw. The "strap-rails" were about 2½ inches wide and ¾ inch thick, laid on 6-inch by 6-inch stringers, to which they were fastened by spikes through their surface and about 12 inches apart. The recurring blows from flange action threw the stringers out of line. This irregularity was corrected horizontally by wedges or keys, driven beside the stringers in jogs in the mud-sills that supported them, and vertically by wooden shims. The track was of such slight construction as to be rightly described as "a hoop tacked to a lath."

This description is not applicable to early railroad construction in the Eastern States, where more approved methods had been derived from English experience. The Quincy tramway of 1826 was laid on granite sleepers 8 feet apart, which were obtained from the quarry that it served. The pine stringers were 12 inches deep, covered with a strip of oak, to which the strap-rails were spiked. The Boston & Lowell Railroad, built in 1835, was a remarkable example of track-construction, with a continuous foundation of parallel dry-stone walls, supporting stone blocks into which oaken plugs were inserted, to which the rails were spiked. By 1845, this form of construction had been abandoned for a track laid on chestnut ties, 7 feet long, 6 inches deep and 31 inches apart, on a bed of gravel two feet in depth. The T-rails weighed 56 pounds per yard, in 18-foot lengths; the joints being secured in "clasp" chairs of 20 pounds' weight. The Boston & Providence Railroad track of 1837 was of a similar construction and, after eleven years of operation, it had been necessary to replace but 750 rails, or only 2¼ per cent. of the whole. The average life of the white-cedar sleepers had been from seven to eight years. On the Western Railroad of Massachusetts, in 1841, 56½-pound rails were laid on sleepers 7 feet long and 7 inches deep, 3 feet between centers. The sleepers rested on longitudinal sills, 8 inches wide and 3 inches thick, supported at the joints by other pieces 3 feet long. Four pieces of this length were also placed under the joint-sleepers.[1]

[1] In the report of the Boston & Lowell Railroad Company, made to the Legislature in February, 1838, it is stated that, "The foundation for the first track of rails is laid with dry stone walls in trenches from 2½ to 4 feet deep and about 18 inches thick. The rails are laid, part on stone blocks, and a small part on stone

Sleepers of unhewn timber were apparently in general use, as the stringer-track of the Mohawk & Hudson Railroad, built in 1831, is described as laid on sleepers 8 feet long by 7 inches in diameter and 3 feet between centers, with a strap-rail $\frac{9}{16}$ inch by $2\frac{1}{2}$ inches, "with the upper curve rounded to $1\frac{7}{8}$ inches in width." The sleepers rested on stone blocks in a bed of broken stone. The tramway of the Delaware & Hudson Canal & Railroad Company in 1829 is described by Mr. Allen, its chief engineer, as "formed of rails of hemlock timber in sections 6 by 12 inches, supported by caps of timber, ten feet from center to center. On the surface of the rail of wood was spiked the railroad iron — a bar of rolled iron $2\frac{1}{4}$ inches wide and $\frac{1}{2}$ inch thick." It is not surprising that such a track should have been insufficient to support locomotives weighing seven tons on four wheels.

The gradual extension of the Baltimore & Ohio Railroad represented the continuing development of track-construction, from longitudinal sills of granite, laid in trenches filled with broken stone, to stone blocks supporting wooden stringers, and to "the log-rail, formed of trunks of trees, worked to a surface on one side to receive the iron and supported by wooden sleepers." The original strap-rail was $2\frac{1}{2}$ inches wide by $\frac{5}{8}$ inch thick, in lengths of 15 feet, beveled on the ends and pierced with 11 oblong holes.[1]

blocks and sleepers, all of which are supported on the trench-walls above described. The stone blocks are 3 to 4 cubic feet each. The stone sleepers are 7 feet long and average 8 to 10 inches square. The wooden sleepers of chestnut and white cedar are 7 feet long, 7 to 8 inches in diameter. This track is mostly laid with rails of the fish-belly pattern, and is set on chairs which are fastened to the blocks and sleepers above described." F. J. Wood, "Discussion on Railway Development." Trans. Am. Soc. C. E., December, 1911.

[1] In a report dated December 1, 1829, Colonel Long, chief engineer of the Baltimore & Ohio Railroad Company, describes the track-construction as follows: "The tops of fills and bases of cuts were alike made 26 feet wide, with side-slopes of $1\frac{1}{2}:1$ for fills and $1:1$ for cuts. Of the 26 feet, 20 were macadamized with broken stone of 2 and $2\frac{1}{2}$ inch size, laid to a depth of 4 inches. Trenches were dug through this pavement, 4 feet apart, to receive the ties and at each end a pit was dug, 18 inches long, 12 inches wide, and 12 inches deep, which was filled with rubble to form a foundation for the tie. The ties, of locust and cedar, were 8 feet long and 7 inches in smaller diameter, and were notched to receive the wooden rails, the outer edge of the notches being placed to a true spacing of 5 feet. The wooden rails were of 6-inch by 6-inch Southern heart-pine, in lengths of from 15 to 40 feet, and were set in the notches with keys. The iron rails, on which the wheels were to run, were of wrought iron, $\frac{5}{8}$ inch by $2\frac{1}{2}$ inches and 15 feet long, appropriately rounded on their upper sides, and perforated with elliptical holes about 15 inches asunder. At the joints they were scarfed on an angle of 60° with the sides, and laid on a plate $\frac{1}{16}$ inch thick. The nail-holes were counter-sunk, allowing the nail-head to be driven below the touch of the wheel, while the elliptical shape of the hole took care of expansion and contraction. For a width of 9 inches on the inner side of each wooden rail, coarse broken stone was laid, leaving a space of $2\frac{1}{2}$ feet in the center which was filled with finer broken stone to form a path for the horses. An alternative construction of stone rails was contemplated, in which case the stone rails were to rest on continuous rubble walls built in trenches to a depth below frost. Wooden rails were adopted for first construction, because it was believed that the fills would not sufficiently compact to receive such permanent work as stone, for 4 or 5 years." F. J. Wood, "Discussion on Railway Development." Trans. Am. Soc. C. E., December, 1911.

Stringer-track continued in general use in New York until 1847, and in the Southern States for ten years afterward. Under the rolling effect of passing wheels, the strap-rail tended to break at the spike-holes and to buckle up in "snake-heads" at the ends, where it was mitred to lessen the wear. This led to the substitution of the "chub-rail," which was wider and thicker than the strap-rail and was rolled with a low flange on the inner edge, through which it was spiked to the stringer, instead of through the upper surface. Rails of this pattern were in use in Georgia as late as 1870, weighing from 30 to 40 pounds per yard. There was also a pattern with a double flange of an inverted U-section, spiked to the stringer alternately through the inner and the outer flange. Rails of this pattern, rolled at Mt. Savage, Maryland, in 1844, weighed 42 pounds per yard.

The bull-head rail never found favor in the United States. In fact, it was anticipated by the inverted "T" pattern, usually known as the "T-rail" or "flat-base" pattern; as the upright T-rail had been displaced in England by the bull-head pattern. The inverted T-rail or "pear-head" rail was an American idea, having been invented, in 1830, by Robert L. Stevens, who had the first lot rolled in England. In May, 1831, this lot of five hundred rails, in lengths of 15 feet and weighing 31 pounds per yard, was probably laid on the Camden & Amboy Railroad. The next lot was of a 40-pound section, 3½ inches high, 2⅛ inches wide on top and 3½ inches on the base, in 16-foot lengths.

In 1844, rails of this pattern were rolled in the United States at Danville, Pa. In 1846, T-rails were substituted for strap-rails between Baltimore and Washington. By 1850, 9021 miles of track had been laid with this pattern, and 30,628 miles by 1860. The T-rail was re-invented or rather introduced into England, in 1836, by C. B. Vignolles, who was perhaps the Vignolles who practiced surveying at an early date in South Carolina and published an excellent map of that State. Although the T-rail has been generally adopted elsewhere, it has not replaced the bull-head rail in Great Britain. In Ireland, however, the "Vignolles" or "flat-bottomed" section, weighing 95 pounds per yard, is the standard pattern on two of the principal lines.

Up to 1860, the rails in common use in the United States weighed 50 pounds per yard. By 1870, the usual weight was 60 pounds. With the introduction of steel rails and the requirements of heavier traffic, there was a further increase to 65 and 70 pounds. In 1883, Dr. P. H. Dudley designed an 80-pound section, 5 inches high, which was 66 per cent. stiffer than the 65-pound section, 4½ inches high, with only 23 per cent. more metal. In 1892, this rail was replaced on the New York Central lines by another section of his design weighing 100 pounds per yard and 6 inches high. In 1915, the Pennsylvania Railroad Company adopted a standard section weighing 125 pounds and 6½ inches high. On the Central Railroad of New Jersey, rails of the same height, weighing 135 pounds, have for some time been in use. Recently, the Lehigh Valley Railroad Company has laid rails, on mountain-divisions with heavy grades and sharp curves, weighing 136 pounds and 7 inches in height.[1]

The length of rails was increased in the United States, about 1859, from 16 to 30 feet. The standard length as prescribed by practical considerations is 33 feet. Longer rails are more liable to defects in rolling and in straightening them. It is inconvenient to transport rails over 33 feet in length on a flat car of standard length; and a larger force of men is required in loading, unloading and distributing them. Notwithstanding these disadvantages, there is an increasing tendency to the use of 45-foot lengths, in order to diminish the number of rail-joints, and rails are even rolled in 60-foot lengths. In laying these longer rails, there should be a somewhat greater allowance for contraction and expansion, for which, 33-foot rails usually require a space between rail-ends of $\frac{3}{8}$ inch in frosty weather and $\frac{1}{16}$ inch or less on a hot summer day.

As long as the stringers were merely intended to preserve the road from being cut into ruts by cart-wheels, they were laid flush with its surface. But as the cast-iron flanged plates and the flat tire were replaced by the edge-rail and the flanged tire, the track was raised upon the surface of the road. It was then held in line by loading or "ballasting" it with the broken stone that was in common use for building macadamized roads and which still permitted of horse-traction. With the heavier loads accompanying steam-traction, the track was raised upon the ballast for a better foundation.

Rail and Joint Fastenings

A suitable connection of the rail-ends and a sufficient support of the track at these weakest points, have presented the most serious problems in track-construction. In Great Britain, the conformation of the bull-head rail required an additional base for its attachment to the sleeper. This was provided in the heavy chair and wooden key which are essential to the use of this pattern of rail. In the United States, the flat-based pattern in general use at first rested at the joints only on plates through which the rails were spiked to the ties. These narrow plates were superseded by a square plate of wider dimensions, with the middle part of the edges turned inward into lips. Subsequently the plate was transformed into a chair with a continuous lip rolled on its surface. A track laid in this manner soon begins to work loose at the joints. R. L. Stevens sought to remedy this defect, as early as 1830, by the invention of a splice, or fish-plate, bolted through the rails at the joint.[2] The light rail-section then in use was not well suited for an iron splice to fit in its web with a depth

[1] For Standard Rail Sections, see Appendix V, Table I.

[2] The invention of the hook-head spike is also attributed to Stevens, as well as the rail of inverted "T" section.

sufficient to give the necessary strength at the joint, and the value of this device was not at first appreciated.

With the joint supported on a tie or sleeper, the rail-ends are battered by the passing wheels. To minimize this effect, resort was had in Great Britain, in 1847, to the "suspended" joint, in which the rail-ends projected beyond the chairs and were connected by Stevens' fish-plates filling the space between the chairs. Fish-plates thereafter began to supplant chairs in the United States, though not entirely until about 1870, when the 60-pound rail came into general use. A fastening was at one time in use, known as the "Trimble splice," the joint being suspended and spliced by a wooden bar outside, fitted to the web and flush with the rail head, resting on two ties and bolted through the rails to a fish-plate. Several variations of this splice have since been devised in metal. Intermediate tie-plates made their appearance at a later date. Experience with battered rail-ends has led to the abandonment of the supported joint. But in this country, as in others where the flat-base rail is used, a different arrangement of the suspended joint has been adopted, known as the "bridged joint," in which the fish-plates extend over the two adjacent ties. The fish-plates are of an angular cross-section, or "angle-bars," with the base of the bar extending over the base of the rail to a bearing on the ties. Some patterns are further stiffened by extending the base downward in a vertical flange between the ties. Others are returned under the rail and bolted together, to carry a base-plate covering the ties, as an additional support to the rail-ends. With a supported joint, the fish-plates are usually about 20 inches in length, or as much as 48 inches with a bridged joint. They are fastened through the rail with either four or six bolts and with washers which may be of helical form and of tempered steel, to prevent the nuts from working loose. The holes in the fish-plates are somewhat oblong to allow for expansion in the rails.

On European roads, it is customary to prepare a seat for the flat-base rail with a slight cant inward. In Great Britain, where the bull-head rail rests in a chair on each sleeper, the cant is given in casting the chair. In the United States, rails are generally fastened directly to the intermediate ties by hook-head spikes, though tie-plates have come into use with heavy rails, and especially with ties of soft wood. It was formerly quite generally the practice to use on curves a heavy cast-iron rail-brace spiked close against the outer rail on each tie. The advantage of tie-plates on all the ties was not at first appreciated. By thus doubling the metal bearing-surface, the cutting of the wood-fibers by the rail-flange is prevented, and the life of the tie, in connection with preservative treatment, greatly lengthened. At the same time, tilting of the rail, with consequent widening of gauge, is obviated, and it is found that, by the use of well-designed shoulder tie-plates on curves, not only is the super-elevation better maintained, but it is also possible, in most cases, to dispense with rail-braces.

Ballast

The ballasting of a track differs from the metaling of a macadamized road, inasmuch as the latter includes the surface of the road while the former is intended to bind the surface to the subgrade. The surface-water, which flows over the surface of a macadamized highway, drains through a ballasted railway, and, though similar materials are used, they are differently disposed. In England, this matter is as carefully looked after as the surfacing of a highway. The subgrade for double-track varies in width from 30 to 33 feet in cuts, and 28 to 30 feet on embankments, with a crowned surface falling away six inches to the edges. The drain-pipes in the cuts are laid with open joints a foot below the subgrade, and the trench is filled with broken stone. The drains are connected with bricked-up pits every hundred feet.

The stone should be so hard as to preserve its angular fracture. When crushed, the maximum size of the fragment is fixed by a ring of 1½ to 2 inches in diameter and the minimum at ½ to ¾ inch. The bottom-ballast should be in cubes of 3 to 3½ inches, laid by hand, 9 inches deep on embankments, and, in cuts, 6 inches at the center line and 12 inches at the edges, to preserve a level surface. It is from 24 to 26 feet in width on embankments and extends over the drainage in cuts. The smaller-sized top-ballast is spread in a layer of about 12 inches, in which the sleepers are bedded to their upper faces. The earlier practice of filling in the ballast to the underside of the rail, carried on heavy cast-iron chairs, has been abandoned. The top-ballast is spread well out beyond the ends of the sleepers to preserve the alignment against horizontal thrusts, and is trimmed to the level of the bottom-layer.

Furnace-slag compares favorably with broken stone as ballast. It costs nothing except for crushing and carriage, while the handling and packing of broken stone adds materially to the expense of using it. Cinder is used in the factory-districts. It more readily absorbs the surface-water than broken stone, especially on a clay subgrade, but is objectionable on account of dust. River-ballast, being composed principally of water-worn pebbles, does not make as steady a foundation as broken stone. Gravel is screened in meshes, 12 to the inch. On account of the dust, the use of gravel and sand is commonly restricted to sidings and yards.

A ballasted roadbed, as understood in England, was rarely to be found in the United States until long after the Civil War. The track was usually laid directly upon the subgrade. If that happened to be clay, sand was distributed along the track from the nearest cut and packed under the "low joints" caused by insufficient drainage. A gravel-bed was a treasure mine and broken stone was an unheard-of luxury. By degrees, the fact became obvious that a well-ballasted roadbed is essential to good track, and that nothing less than 12 inches of suitable material beneath the ties will secure a proper foundation.[1]

Steel Rails. The Bessemer Process

As above described, the railroad track has long since attained its present development, except as to the dimensions and details of its several parts and the character of the materials of which they are composed. The most important change in this latter respect has been in the substitution of steel for iron rails. The rail-sections had been enlarged to meet the requirements of increasing traffic, but the heavier rails proved to be short-lived and caused serious dissatisfaction as to their reliability and the cost of frequent replacement. In 1863, the Pennsylvania Railroad Company made a trial of rails of crucible steel. The cost of this material, and the difficulty of producing a uniform product in masses of sufficient magnitude, rendered its general use impracticable. At this critical period, Bessemer's invention for converting pig-iron directly into steel was applied to rail-manufacture. The first rails from Bessemer steel were laid in England in 1857. Rails of this material had been rolled in Chicago in 1865, but the first rails on a commercial order were rolled in Johnstown, Pa., in 1867.[2] By 1880, renewals with iron rails had virtually ceased.[3]

Viewed as a metallurgical product, the rail, in its early stages, was simply a ball of puddled iron. Its mass was limited to the weight of the ball which could be manipulated by the puddler, and, therefore, to the pro-

[1] American Standard Track

Rails — 85 to 100 pounds per yard.

Ties — 6 by 8 inches by 8 feet, or 7 by 9 inches by 8½ feet; spaced 18 per 30-foot rail.

Ballast — 12 inches under ties.

Ballast required per 1000 feet of Single Track:

6 inches deep	300 cu. yds.
12 inches deep	523 cu. yds.
24 inches deep	1005 cu. yds.

Subgrade — 18 to 20 feet wide for single track and 13 feet between centers for two or more tracks.

—M. L. Byers, "Proceedings International Railway Congress," Berne, 1910.

[2] "Track," A. B. Corthell. Journal Am. Soc. Mechanical Engineers, July, 1914.

[3] Mileage of Steel and Iron Track (Poor's Manual).

Year	Miles, Steel	Miles, Iron	Per Cent. Steel
1880	33,680	81,967	29.1
1885	98,102	62,495	61.0
1890	167,606	40,697	80.4
1895	206,546	28,652	87.8
1900	238,464	19,389	92.5
1903	271,013	15,247	94.7

portionate weight per yard to the length of the rail. This difficulty was measurably overcome by the invention of the mechanical puddler, but this permissible increase in length and weight of section was next restricted by difficulties in rolling heavy sections, which were obviated by increasing the power and strength of the rolling-trains. It was at this point that the manufacture of rails was transformed by the invention of the Bessemer converter in 1856. The magnitude of this change and its effect upon railway transportation can be adequately appreciated only by those whose experience covers that period of transformation. Rail-making then ceased to be empiric. It had become a scientific process and, with the change, the iron-master had become a metallurgist.

The fundamental principle of Henry Bessemer's invention was the reduction of the carbon in cast-iron to the point at which the treated metal would acquire the malleable property of wrought-iron, without losing its characteristic plastic property. In other words, it was the production of steel directly from cast-iron by the diminution of its carbon percentage, instead of producing it indirectly by the addition of carbon to wrought-iron in kiln-made steel or "blistered steel." As it lacked the property of the molecular change of tempering in cooling, peculiar to crucible steel, it was distinguished as "converted steel."

Bessemer undertook to reduce the carbon content of cast-iron to the requisite proportion for steel by depositing the molten metal in a receiver and there "converting" a part of its carbon into carbonic-acid gas by oxidation with air blown violently through its mass. It was found impracticable, however, to reduce the varying percentage of carbon in cast-iron to just the right proportion to constitute steel by this means, as a commercial product. The whole process was accordingly threatened with disaster until Bessemer conceived the idea of completely eliminating the carbon from the melted metal, and then restoring a fixed percentage. This result was attained by the addition of a specific alloy of iron with manganese, known as ferro-manganese or "spiegel-eisen." The reactions thus produced pertain more especially to the chemistry of metallurgy. With this change, the process became a practical triumph. Iron-making was revolutionized in all its phases, as also the manufacture of iron products and the design and construction of engineering works.

Steel Rails. The Open-Hearth Process

Wrought-iron produced from sulphurous ores is known as "red-short," because it is brittle at a red heat. The sulphur contained in iron smelted from such ores is eliminated as a gas in the converter. The phosphoric acid present in iron smelted from phosphatic ores causes "cold-short"; that is, wrought-iron from such ores is brittle when cold. As the Bessemer process does not affect phosphoric acid, phosphatic ores must be mixed in the blast furnace with a sufficient proportion of non-phosphatic ores to render negligible the quantity of phosphoric acid present in cast-iron from such ores intended for conversion. As most of the iron produced in this country is from phosphatic ores, much of the non-phosphatic ores for admixture is from foreign sources with consequently increased cost of the converted product. The Bessemer process has, therefore, been largely superseded by the Thomas-Gilchrist process, in which iron ore or steel scrap, as well as pig-iron, may be used. The melted metal is converted in open receptacles, known as the Siemens-Martin open-hearth, which revolve slowly and horizontally on a slightly inclined axis. Oxidation is effected by the action of gas-flame upon the continually changing surface of the metal, due to this axial rotation. Consequently, the gradual reduction of carbon is secured, which was found impracticable in the Bessemer process. The progressive reduction can be ascertained by successive tests and arrested at any stage of the process. Steel with any desired carbon percentage can therefore be produced. Alloys of tungsten or of other metallic elements can be introduced during the conversion, and high-grade steel produced, which is substituted for crucible steel for many purposes. This process is well suited for the conversion of cold-short iron, as the phosphoric acid is eliminated by combination with the lime in the converter linings into phosphate of lime. The process is, therefore, known as the "basic" process, to distinguish it from the Bessemer or "acid" process, and its product is termed "open-hearth" steel.[1]

The ingot of converted steel has now taken the place of the ball of puddled iron in the mechanical processes of rail-making. It is at this point that defects in the molecular disposition of the metal originate, which persist throughout the subsequent process of manufacture to the serious detriment of the finished product. The defects due to occluded gas bubbles rising to the top of the ingot in pouring and cooling are measurably excluded if the upper portion of the ingot be scrapped. But others are still concealed within the remaining mass, and only disclosed after the rails are in the track. The percentage of such defects is greater with the steel ingot than formerly with the puddled ball of iron, because the metal in the latter was more thoroughly incorporated into a homogeneous mass and at a lower temperature.

The increased length and section of the rail has compelled the substitution of mechanical appliances for manual labor, which has made it possible to so quicken the operation of a rolling-mill train that rails may be projected from it almost as if squirted from a syringe. In furtherance of such productive activity, the ingots are reheated to a temperature of questionable desirability for the future endurance of the rails. Differences of opinion on this point have induced extensive investigations into such heat-

[1] For relative output of Bessemer and of open-hearth rails, see Appendix V, Table VII.

treatment. The subsequent operations of straightening the rail and of punching it for the fastenings have to be performed with such care, as well as its subsequent handling, as to give an impression that the steel rail of to-day is in a far more unstable state of equilibrium, as to its internal structure, than was the iron rail of former days.[1]

Rail-Failures. Standard Types and Requirements

Rail-failures may be considered, for the most part, as divided into crushed or split heads, clear breaks and broken flanges. There are other less numerous defects, as cracks through the web and internal fissures in the head of the rail. The American Railway Engineering Association published statistics for the year ending October 31, 1911, from which it appeared that, for every 10,000 tons of new rail laid, the failures averaged 31.0 tons for Bessemer steel, 20.7 tons for open-hearth steel and, for all rails, 29.0 tons. There was an average of one failure for every 891 Bessemer rails, one for every 1234 rails of open-hearth steel and one for every 941 rails of both kinds. In 1915, out of 634,898 tons of rails, 13,295 were of Bessemer steel. In that year, the comparative failures were reported as 142 of Bessemer to 100 of open-hearth steel.[2]

Rail-failures from internal defects have drawn the attention of metallurgists to the importance of the heat-treatment from the time of reheating the ingot until the last passage of the rail through the finishing-rolls; also to the prevention of surface-defects becoming incorporated in the body of the rail. And further, it is desirable that there should be a recognized classification of the factor of safety in the relation of wheel-loads to the respective dimensions of rails, considered as girders.

The rail, which in its inception was but a metallic surface applied to a wooden stringer, intended only to lessen the rolling friction of passing vehicles, has supplanted the stringer as the weight-bearing element of the track, and fulfills the function of a girder. For one of these purposes it must be hard, for another it must be strong. The hardened surface required of the rail-head must at some point in the composition of the rail merge into the tensile toughness required of the web. The wheel-loads have been continuously increased until they approximately exceed the molecular cohesion of the rail-surface, while the service which the rail itself is thus called on to perform as a beam, induces internal stresses that are developed in lines of cleavage between the texture of the rail-head and the web, and that too often result in broken rails. Then, too, the impact of the swiftly revolving wheel-flanges against the sides of the rail-head brings a fearful horizontal shock upon it. The resulting tendency to turn the rail over is proportionally increased in leverage with the added height

[1] For Specifications of American Railway Association for Carbon Steel Rails, see Appendix V, Table IV.

[2] For Statistics of rail failures, see Appendix V, Table VIII.

of the rail. It may be said that no such combination of services is required of any other metallic appliance and that, taking all of its functions into consideration, the relative sufficiency of the rail for these purposes controls the standards of construction in every other department of railway operation.

The chemical composition of the metal, its heat-treatment in the ingot and its physical treatment in the manufacture, all have a bearing upon the efficiency of the rail when placed in the track; yet as to neither of these matters is there a satisfactory agreement among metallurgical experts.[1] Nor is there an agreement between railroad managers as to the outlines or dimensions of rails of equal weight per yard as to the height, or to the width of base, or of the relative distribution of material respectively in the head, the web and the base of the rail.

At one time, the mills had no less than 119 different patterns of 37 different weights per yard. The cost of production might be sensibly decreased by the general adoption of fewer types of standard sections. Efforts have been made to this end by engineering associations. The American Society of Civil Engineers appointed a committee to report upon standard sections from 40 to 100 pounds per yard, varying by increments of five pounds per yard. Its report was adopted in 1910 and it has been estimated that, up to 1914, 75 per cent. of the product of American mills was in sections of that type. In 1912, the American Railway Association provisionally approved two types of sections varying in weight from 60 to 100 pounds per yard, for which it was claimed that they could be finished at a lower temperature than was practicable with the types recommended by the American Society of Civil Engineers. The American Railway Engineering Association has since proposed a different type of sections varying from 89.96 pounds to 138.52 pounds per yard. A comparison of these types as to dimensions and distribution of metal is given in Appendix V, Tables I and II.

[1] SPECIFICATIONS AS TO CONSTITUENTS OF CONVERTED STEEL FOR RAILS

	CARBON CONTENT PER CENT.	PHOSPHORUS MAXIMUM PER CENT.
British Engineering Standards Committee, 1907	0.35–0.50	0.075
Am. Soc. C. E., 1907. Bessemer steel	0.55–0.65	0.085
Am. Soc. C. E., 1907. Basic steel	0.65–0.75	0.050
Am. Soc. C. E., 1914. Bessemer steel	0.40–0.55	0.10
Am. Soc. C. E., 1914. Basic steel	0.53–0.75	0.04
Am. Soc. for Testing Materials, 1907	0.45–0.55	0.10
Am. Ry. Engineering and Maint. of Way Asso.	0.75–0.85	0.03
Am. Railway Association, 1908	0.37–0.56	0.10

Proportion of carbon to vary with weight per yard.

The difficulty in arriving at a common standard for rail-sections arises principally from a difference in the conditions to which the track is submitted. On a line with heavy traffic and considerable short curvature, a rail is required with more metal in the head than is required under less strenuous conditions, and, if the head is to be thicker, the base of the rail must be thicker also, to insure a sound rail in its manufacture. It was to meet this variation in conditions that the American Railway Association recommended two standard types. The sections for different weights per yard differ so little in these respects that it would seem feasible to arrive at such a common understanding concerning them as would enable the mills to keep rails of standard sections in stock, and the fish-plates and other accessories as well. The general specifications recommended by the American Railway Association represent a possible compromise.

Track-work in England. Ties or Sleepers

The care taken in ballasting an English railway is also given to the other elements of which the track is constituted. The rails are supported on each sleeper in a cast-iron chair from 15 to 16¼ inches in length and from 7 to 8 inches in breadth, weighing from 45 to 56 pounds; in some cases, resting on a layer of felt. The inside-jaw bears well up under the head of the rail, and the rail-seat is so molded that, when the rail is keyed against the inner jaw, it is slightly tilted inward and will keep its position if the key should work out. The inside-face of the outer jaw may be corrugated, to give a better grip to the key. The chair is secured to the sleeper by two ⅞-inch spikes and by two treenails of oak, tapering from 1½ to 1¼ inches, alternating diagonally in the chair, or ¾-inch screw-bolts are substituted for the treenails; all being driven in holes previously bored in the sleepers. The bolts screw into nuts with fangs or projections forced into the bottom of the sleeper, to prevent the nut from turning. The wooden key is from 6 to 7 inches long and from 2 to 2⅜ inches thick, varying in depth from 2½ to 3$\frac{7}{16}$ inches according to the pattern of the chair, the sides of the key being parallel or slightly tapered. The keys and treenails are of oak or teak, usually compressed in dies. Some use is also made of a key of steel-plate, pressed in a double-arched fold with the edges turned on the back, so as to form a tapering slot. By driving a steel wedge into this slot, the key is expanded in the chair and against the rail, forming a powerful double spring. On sharp curves, where a "check-rail" or guard-rail is laid, chairs of a special pattern hold the two rails firmly in place.

The rails are generally laid with suspended joints, opposite each other, and but rarely with "broken" or "staggered" joints. The joint-ties, which in some cases are of the exceptional width of 12 inches, are spaced as closely together as will admit of proper tamping. The fish-plates, fitting between the chairs, are from 18 to 20 inches in length, from 1 to 1¼ inches in thickness, and weigh from 22 to 36 pounds per pair. They are punched for four bolts, $\frac{7}{8}$ to $\frac{15}{16}$ inch in diameter. The bolt-holes, which were formerly for square or for round-necked bolts, are now more uniformly for bolts with necks of a pear-shaped or oval section. Allowance is made for expansion in the fish-plates as well as in the rails. The plates are rolled of a mild steel, toughness being its leading characteristic.[1]

Sleepers in England are usually of Baltic pine or fir, 9 feet long, 5 inches thick and 10 inches wide. They are sawed to a length, bored for the fastenings, machined for the rail-seat and then treated with preservative solutions. The spacing of sleepers at the joints varies between centers of chairs from 23 to 28 inches; otherwise it varies with the length of the rail. Variations in these respects are noted in Appendix V, Table IX.[2]

Pot Sleepers. Steel and Concrete Ties

An important change in track-material, known as the "pot sleeper," was introduced, in 1854, into Egypt, where timber was scarce and costly. This form of track-support is simply an enlarged cast-iron chair like an inverted tray; its shape being intended to keep it in position in the desert sand. The sleeper is formed of two of these chairs kept to gauge by a tie-bar. The flat-bottomed rail is keyed to the pots, which are tamped through large holes in their sides. Sleepers of this kind are used also in Hindustan. The pots are usually 25 inches long, 13 inches wide, $5\frac{1}{8}$ inches deep under the rail and from $\frac{5}{8}$ to $\frac{3}{4}$ inch thick.

The substitution of a metal sleeper or tie for wood really began when converted steel came into general use on the European continent. The steel is rolled in plates from 12 to 14 inches wide, by $\frac{1}{4}$ inch thick at the edges and $\frac{5}{16}$ inch at the center line, pressed into the shape of an inverted trough from 3 to $3\frac{3}{4}$ inches in depth. A tilt is given to the rail-seat and

[1] For Standard Specifications of Fish-plates in the United States, see Appendix V, Tables V and VI.

[2] Usual Dimensions of Sleepers

Country	Length, Feet	Width, Inches	Thickness, Inches
Great Britain	9	10–12	5
France	$8\frac{1}{2}$	$8\frac{5}{8}$–$9\frac{1}{2}$	$5\frac{1}{2}$–6
Germany	$8\frac{1}{2}$	$9\frac{1}{4}$	$6\frac{1}{4}$
Belgium	$8\frac{3}{4}$	11	$5\frac{1}{2}$
India ($5\frac{1}{2}$ ft. gauge) . .	$9\frac{1}{2}$–10	10	5
United States	8–$8\frac{1}{2}$	8–9	6–7

In the Southern part of the United States, while the track was of 5-foot gauge, the ties were nine feet in length and from ten to twelve inches in width, where pine timber was abundant.

the ends are curved downward to insure a firm bed in the ballast. The flat base of the rail is secured by keys to projections punched out of the plate. Metal sleepers were introduced in 1881 into Switzerland, where 70 per cent. are now of metal, 9 feet in length and weighing 160 pounds. 26,000,000 had been laid in Germany up to 1905. On the government railway system in Cape Colony 700,000 have been used. The most extensive experience with steel ties in the United States has been on the Bessemer & Lake Erie Railroad, where about 850,000 were in use up to 1913. The most recent type is rolled of an inverted "T" section, $5\frac{1}{2}$ inches high, 8 inches wide at the base, $4\frac{1}{2}$ inches at the top, $8\frac{1}{2}$ feet in length and weighing 180 pounds; it is secured to the rail by bolts through its upper flanges and through clips extending over the base of the rail. Each pair of 30-foot rails is supported by 20 ties. To prevent corrosion, they are dipped in hot tar. The insulation of the track-circuits gives rise to no difficulty.[1]

The value of steel ties as a general substitute for wooden ties is as yet a matter of first cost, which in Europe is about double. This statement of itself indicates that an enormous increase of capital would be required to accomplish such a substitution; so that the life of a metal tie should be at least double that of a wooden one to justify the change, even disregarding the intermediate interest-account on the additional investment. The economic life of the metal sleeper is as yet undetermined. The effects of corrosion are to be balanced against those of vegetable decay, as is the case with steel car-bodies. There is a greater comparative cost for handling and storing, with less uniformity as to standard dimensions and a greater multiplicity of parts. In countries where suitable timber is scarce or is exposed to the ravages of the termite, the steel tie may have the preference; but in Great Britain, where the raw material is abundant and they are manufactured on an extensive scale for export, they have not superseded the imported wooden sleeper, although the latter is subjected to an expensive preservative treatment.

Experience with beams of reinforced concrete has suggested the use of that material for railroad ties. Its component elements may be found in abundance where timber is scarce and may be molded in the immediate vicinity of the railway work, with a saving of transportation and handling. It offers the same resistance to the ravages of insects that sheet-steel does and is not subject to corrosion, but its susceptibility to disintegration is yet to be ascertained. On the whole, it would appear that wooden ties must long continue in use and that economy must be sought rather in prolongation of their economic life than in their replacement by the substitution of other materials.

[1] For further information as to details of track-construction in Great Britain, see "Modern Permanent Way," C. J. Allen, London, 1915.

Tie-timber and Preservative Treatment

The Census Bureau reported that, in 1907, the consumption of tie-imber in this country amounted to 153,700,000 ties, of which 23,500,000 were for new track. About one-half of this number were of oak, about one-fourth of Southern yellow pine and the remainder was chiefly of chestnut, cedar, Douglas fir, cypress, tamarack, Western pine and loblolly pine; with a local use of lodge-pole pine, gum, beech and spruce. Assuming the average yield from an acre of forest as 240 ties, the total consumption of timber for this purpose, in 1907, deforested about 1000 square miles of forest lands. Attention has been paid by a few railroad managements to experimental tree-planting but, as it takes at least twenty years for trees of even the softer woods to attain the proper size for tie-timber, it is plain that the time is approaching when ties will have to be imported into the United States at a cost that will equal that of metallic ties. One-seventh of the cost of maintenance-of-way is for ties, and the expenditure for tie-renewals is about double that for the replacement of rails.[1]

To a considerable extent there has been a wastage from hard treatment, and it is only in recent years that such attention has been given to this matter as has long prevailed in countries where timber is less abundant and not so cheap. Under ordinary conditions, ties of oak or pine of standard quality may, for the most part, remain in the track from five to eight years, varying with the effects of traffic. A greater economic life is claimed for certain species of oak, chestnut and cedar that are not in general use. In 1908, 82 per cent. of the ties in use were of hewn timber. There is a preference for those hewn singly from the cut, and it is only with the scarcity of timber that sawed ties have become acceptable.

Recourse to preservative treatment has become necessary from the progressive deforestation in civilized countries. The purpose of preservative treatment is to arrest decay; which is itself a decomposition of cellular tissue by parasitic fungous growth. The germs from which this growth is developed may either have been dormant within the timber and only have acquired activity with the death of the tree, or they may have been introduced superficially through the agency of moisture. Protection from the latter cause had long been practiced by ship-builders and by other timber-workers. Such superficial treatment was greatly impaired by any subsequent exposure of unprotected surface by mechanical operations upon the timber, nor did it affect the action of germs already present within its cellular structure.

In the early railway era, the comparative scarcity of suitable timber

[1] In ten years, 1865 to 1875, renewals of rails amounted to 28.9 per cent. of the total cost of maintenance of roadway and structures, and renewals of ties to 11.7 per cent. In the three years, 1907–1909, rail-renewals made up 5.1 per cent. of this account and tie-renewals 14.7 per cent. "Railway Development in the United States," W. D. Taylor. Trans. Am. Soc. C. E., December, 1911.

of native growth in Great Britain soon directed attention to the importance of prolonging the usefulness of sleepers by superficial treatment for their preservation. Pitch had been the only protective material available for this purpose until the production of coal-tar as a by-product in the manufacture of illuminating gas. In 1838, Burnett patented the use of oil of coal-tar, known as "creosote oil," for the preservation of timber by steeping it in open tanks. He soon adopted the "Bethell" method of placing it in closed tanks, forming a partial vacuum by steam-condensation to remove the sap, and then injecting the liquid under pressure. By this improvement, the oil not only served for superficial protection but also as a germicide for the destruction of internal vegetable fermentation. A "vulcanizing" process was also tried, which consisted in sterilizing the timber by submitting it, in retorts, to heat sufficient to char its surface, but this process was found to be less effectual than creosoting, besides diminishing the strength of the timber.

About 1837, the French treated timber by expelling the sap under hydraulic pressure and using sulphate of copper as an antiseptic. About 1878, this process was abandoned in favor of oil which, for a time, the State Railway management mixed with chloride of zinc. Now, both in France and in Great Britain, all sleepers are creosoted. Prior to the treatment, they are machined for rail-seats and for spike-holes or bolt-holes, as the effect of the treatment is comparatively superficial, and the exposure of a fresh surface to parasitic growth is thus diminished. Screw-bolts damage the timber less than spikes do, and fang-bolts less than either. Old spike-holes are plugged up, and handling the sleepers with picks is forbidden. The rail-chairs rest upon a layer of felt, to protect the sleepers from abrasion. On the British railways, from 28 to 30 pounds of oil are used per sleeper, with an average life of 16 to 20 years. The French inject from 30 to 40 pounds, and even 60 pounds, and claim from 25 to 30 years of life. In France, about 2,600,000 sleepers were used in 1900, while, for the years 1878–1885, the renewals averaged 3,000,000 per annum, with less track-mileage. A saving of 3,000,000 annually is attributed to improvements in the processes employed. In a single year, 14,126,000 cubic feet of timber were treated for railway purposes.

Mineral salts in solution are also injected by the Bethell process, and very generally in Germany, where railroad ties or sleepers were treated either with corrosive sublimate or with sulphate of copper. Only chloride of zinc is now used, and recently that has been abandoned on the State Railways for creosote oil. The methods employed are either impregnation with chloride of zinc and tar-oil, or creosoting after seasoning and drying in ovens, or after desiccation in hot tar-oil. Ties treated by the zinc-creosote process last from 12 to 18 years, and creosoted ties from 24 to 28 years.

"Burnettizing" was introduced into the United States in 1850 at

Lowell, Massachusetts, and was there worked by the "Bethell" process until about 1862; but apparently with indifferent success, as it was abandoned for a time for the "Kyanizing" process with chloride of mercury. Now, however, it is much used with chloride of zinc and, to some extent, in combination with other substances, principally with creosote oil. These several combinations are respectively known as: the "Rutgers" process, but little used, in which the two liquids are injected in a mixture; the "Allerdyce" process, in which chloride of zinc is injected first and then the creosote oil; and the "Card" process, patented in 1906, in which the two liquids are mixed and maintained under pressure by a centrifugal pump. There is also the "Wellhouse" process, a combination of chloride of zinc, tannin and glue; and the "Thelmany" process, in which sulphate of copper is used. Chloride of zinc has supplanted other mineral salts as an antiseptic because of its cheapness but, being soluble in water, it eventually leaches out of the ties. It is for this reason that, in the modified processes, it is used in combination with creosote oil, which is insoluble in water. The same end is sought in a cheaper way by mixing chloride of zinc with tannin and glue.

The relative economic value of chloride of zinc and of creosote oil depends upon the average annual cost of renewal during the life of ties so treated. In 1899, it was estimated that, in the United States, the average life of ties treated with chloride of zinc was about 10 or 12 years, and of ties treated with oil from 15 to 30 years, but at three or four times the cost. The wide range of life given by the oil-treatment, as here stated, makes this comparison of little value. The relative value of the modified process can only be established after ties treated by them have been in service at least as long as were those that have been treated with chloride of zinc.

In any comparison of the value of oil as compared with mineral-salts, account should be taken of the character of the timber used for ties; as some kinds take more oil than others. Red oak, pin oak, beech and tamarack absorb less than 22 per cent. in volume; sweet gum, chestnut, sycamore and poplar, 23 per cent. to 30 per cent.; tupelo gum, short-leaf pine, cypress, birch and cottonwood, over 30 per cent. The success of the oil-treatment depends also upon the character of the oil. Real "creosote oil" is the heavy distillate of coal-tar, obtained at a temperature ranging from 480° to 760° F., and the proportion between its chemical constituents varies with the temperature at which it is distilled. It is assumed that it should contain at least 5 per cent. of tar-acids and 25 per cent. of naphthalene to secure its insolubility in water; naphthalene being the efficient germicide.

Proper seasoning of the ties is of importance in their preservative treatment. In Great Britain, they are thoroughly dry-seasoned, but in the United States they are usually only steam-seasoned. It would seem that dry-seasoning is in itself a preservative, by preventing checking and the admission of extraneous germs with the moisture. In treating freshly cut timber with oil, it would be well to season it with oil instead of steam; but, if steam be used, then not for so long a period or at so high a temperature as to diminish its strength.[1]

Upon the Chicago & Northwestern Railway, there are two very considerable plants for treating ties. One of these has a capacity of 800,000 ties per annum and the other of 600,000; the timber being of pine, spruce or fir. In the more recent plant at Riverton, Wyoming, the retort is 6 feet in diameter with a track of 24½-inch gauge, admitting at one time a train of 16 cars, each containing from 30 to 32 ties. Live steam is first admitted and provision is made for discharging the condensed sap. A 20-inch vacuum is obtained in 30 minutes and held for 45 minutes. The vacuum pump is then shut down; the solution of .05 chloride of zinc flows in and is kept at a temperature of 150° F. by heating-radiators. When the retort is full, an additional amount of 2.5 solution, containing half a pound of dry chloride for each cubic foot of timber, is forced in from the pressure tank and held under 150 pounds' pressure for about four hours. The air in the pressure-tank is then used expansively for forcing the unabsorbed solution back into the working tank. With four charges in 24 hours, the average output is about 50,000 ties per month.[2] The Atlantic Coast Line has an extensive plant at Gainesville, Fla., for the treatment of yellow-pine timber with creosote oil, which is considered preferable for the harder woods. Ten pounds of oil per cubic foot are usually required for pine ties and twelve pounds for softer woods. Treated ties should be laid sap-side up and a dating-nail driven in each tie as it is laid.

According to a census report in 1911, in 401,653 miles of track, the annual renewal of ties amounted to 135,053,000, or an average life of somewhat less than nine years. Of this number, 23 per cent. had been preservatively treated, and for the most part with chloride of zinc. Upon the Atchison, Topeka & Santa Fé lines, ties have been treated since 1885. Up to 1916, with 30,422,416 ties in the tracks of the parent system on a mileage of 9552 miles, over 80 per cent. had been treated. As a result, the annual renewal is less than 200 ties per mile, indicating an average life of fifteen years. Spike-holes are bored and rail-seats are adzed. Each tie is stamped with the date and kind of timber, and the weight of rail for which it was bored.[3]

Track Efficiency. Wheel Loads. Tie-spacing

Although the substructure of a well-constructed road deserves the name of "permanent way," its track or superstructure may as appropriately be

[1] "Preservation of Timber," F. A. Kummer. Trans. Am. Soc. C. E., December, 1900. "Preservation of Timber in Europe," O. Chanute. *Ibid.*, June, 1901. "Timber Preservation," W. Buehler. *Ibid.*, March, 1911.

[2] "New Tie-treating Plant on the Northwestern Railway," L. J. Putnam. Engineering News, April 20, 1916.

[3] Railway Age Gazette, September 22, 1916.

termed, in contradistinction, a "temporary way"; for it undergoes incessant deterioration and restoration. Its distortion and disintegration vary with variations in the character and extent of the train-service. The ballast is ground into dust as the ties rock in their beds; the ties themselves are shaken and split and their decay thereby hastened. The rails become bent and loosened in their fastenings, their wearing surfaces deformed and their ends battered down; while fractures occur unexpectedly from internal molecular disintegration. All the refinements proposed in the details of rail-joints and in the spacing of ties, apparently add no material advantages to a track of standard construction with bridged joints on a deep foundation of suitable ballast and well drained. At last, it is a question of maintenance, of incessant labor and vigilance on the part of an army of trackmen.

What are the shocks and strains by which the efficiency of the superstructure is thus diminished? The recurring waves of deflection under passing trains rack the ballast, ties and joints. The rolling-friction of the wheel-treads wears away the heads of the rails, and the hammering effect of foot-pounds of energy beats down their ends. The swerving of trains from side to side throws the track out of line on tangents. At every curve, this pressure is intensified by the centrifugal force which exerts a tendency in the wheels to climb the outer rail, or to overthrow it, or to force it outward by shearing the spike-heads. Under such conditions, it is not surprising that the superstructure of a railroad should be virtually reconstructed within a decade; and the character and extent of each factor in this combination of destructive elements should be carefully weighed in counteracting their effect upon each component part of that superstructure.

Primarily, the track should support the weight of the trains without being thereby deformed. This weight is distributed among the wheels under a train; and the depth of the ballast, the dimensions and spacing of the ties and the weight and form of the rail-section should be conditioned by the heaviest weight borne by any passing wheel; that is, by the driving-wheels of the locomotive. In this respect, the railroad superstructure is submitted to severer tests in the United States than elsewhere. Here, the axle-load of 50,000 to 60,000 pounds is to be supported by a tie with a bearing surface of 5.5 to 6.4 square feet, which is a static load of 7800 to 10,900 pounds per square foot. In Great Britain, the average axle-load of about 38,000 pounds is supported by a sleeper with a bearing surface of 7.5 to 9 square feet with a consequent static load of 4300 to 5000 pounds per square foot, or about one-half of the weight that a tie is expected to support in the United States; and on a ballasted road-bed far more carefully prepared than is customary in this country.

There is a similar disparity as to the load concentrated upon the rail as a girder. In the United States, upon a rail-length of 32 to 40 feet, there is a load ranging from 230,000 to 330,000 pounds, and in the case of an articulated locomotive, in a length of 40 to 67 feet, of 468,000 to 616,000 pounds on the opposing rails. In Great Britain, for a length of 32 to 40 feet, the average load would be about 145,000 pounds, and in no case more than 190,000 pounds.[1] As ties are usually spaced in the United States, 2640 to the mile or 24 inches between centers, a rail-length of 32 to 40 feet is supported by 16 to 20 ties with a bearing surface of 88 to 132 square feet, and, with the ordinary locomotive, would sustain a distributed load of 1700 to 3700 pounds per square foot. As sleepers are spaced in great Britain and with the locomotives there in use, the same rail-length would be borne by 12 to 16 sleepers, carrying a distributed load of about 1200 pounds per square foot and not exceeding 2000 pounds. The additional thickness of one inch in the American tie should, however, be considered in this comparison.

Upon the Atchison, Topeka & Santa Fé Railroad system, the spacing of ties leaving a uniform distance between them is viewed with favor. Squared ties, 7 by 9 inches, are spaced slightly more than 11 inches between their edges, not centers, so that there are twenty ties under a 33-foot rail. Ties with an 8-inch face are spaced 13.8 inches. The spacing is regardless of joints, where no reinforcement extends below the base of the rail. Where the spacing is uniform with ties of 9-inch face, the joint-fastening will be supported either by two ties near its ends, or by one tie near its center, thus insuring either a suspended or a supported joint.[2]

Rail Stresses and Wear

The track does not merely support a load at rest. It should also retain its stability under a train in motion; and here are encountered some of the most serious difficulties in railway operation. A wave of deflection, preceding each train, causes undulations in the rails which lift the track from the road-bed, to be rammed back by blows repeated from each wheel in the train. These undulations are not entirely transmitted from rail to rail. They are partially arrested at each rail-end; part of their energy being dissipated in racking the rail-fastenings. Much ingenuity has been exhibited in designing fastenings that would either resist the disturbing effects of the wave of deflection or that would facilitate its passage from rail to rail. There has been an evolution from a simple bearing-plate to the lip-chair and to the fish-plate to meet these requirements. The fish-plate has been stiffened in design and enlarged in dimensions until it has become an appliance more appropriately called a joint-bar. The same attention is given to its metallurgical composition and treatment as is given to the manufacture of the rails that it connects. It has been widened until it covers the entire surface of the web between the head and the rail, and has been extended over the base to a support on the ties. Still, the wave of deflec-

[1] For Wheel Loads of American Locomotives, see Appendix V, Table X.

[2] Railway Age Gazette, September 22, 1916.

tion racks the fastenings at their weakest point, the bolts; as is shown by the difficulty in keeping the nuts from working loose. An army of men is daily employed in tightening them up, despite the use of jam-nuts and spring-lock washers.

The attention given to the design and manufacture of the elements of construction and the thoroughness with which the work is done, have given the English standard track an enviable reputation. The same thoroughness characterizes the drainage, the sodding of slopes and the other features of an English roadway. Railway practice on the continent of Europe has followed English methods in track-construction, as in other matters; except as affected by the general preference for rails of the inverted "T" or flat-base pattern. In some respects, the bull-head rail presents an apparent superiority to the T-rail. Its joint-connections combine the advantages of the fish-plate and of the chair. In further combination with a heavy chair on each sleeper and the wooden key, there is a resilience in the track constructed after the British fashion which American track does not possess in the same degree. And yet, even in Great Britain, with comparatively lesser wheel-loads, the problem of transmitting the wave of deflection from rail to rail unimpaired, has not been satisfactorily solved.

In the solution of this problem, other issues are presented with reference to the relative position of the joint in opposite rails and to the manner in which they are supported by the sleepers or ties. It has long been customary in the United States to lay the rails with broken or staggered joints; probably because the track stood up better on inferior ballasting than when the opposite joints were on the same tie. In Great Britain, however, rails are usually laid with even joints, and rails of shorter lengths, or "make-up" rails, must be frequently introduced, in order to preserve the even joints. On either plan, low joints are common on track that is not carefully maintained.

Nor is it possible, even with the most approved forms of construction, to prevent the rails from acquiring a permanent set, consequent upon the incessant rolling of heavily-loaded wheels upon them. Track-inspection by Dr. P. H. Dudley, with an autographic track-indicator, upon 10,000 miles of track on the main lines of the New York Central and the Pennsylvania railroads, established the fact that rails in service from three to five years become permanently set. With even joints, they are low at the joints and high at the centers; with broken joints, they are low at the joints and centers and high at the quarters.

It is estimated that a steel rail of standard composition and manufacture, weighing from 60 to 80 pounds per yard, will withstand the passage of 300,000 to 500,000 trains, with a loss of ten to fifteen pounds of metal and a wear of $\frac{3}{8}$-inch to $\frac{5}{8}$-inch on the rail-head, though many rails exceed this minimum.[1] But long before the rails are in this condition, they are re-

[1] "Railway Location," Wellington. Page 119.

moved to sidings and to industrial branch-lines, when the incessant hammering by passing trains has effected a permanent depression in their surface at the joints, which intensifies the general deterioration of the track.

A test was made of the resistance of track to flange-pressure on a section laid with new, dressed-chestnut ties, and a rail of 100-pound section spiked to tie-plates on each tie. Under these conditions, it was found that a side-pressure of 10,000 pounds would overturn the rail. In fact, the rail does not overturn, because it is prevented from doing so by the weight of the locomotive. For the rail to be in equilibrium, the side-thrust must equal one-half of the load on the driving-wheels plus the resistance of the spikes. When this limit has been reached, the rail will overturn. As the weight of the locomotive increases, the percentage of thrust on the wheels necessary to overturn the rail decreases. Theoretically, the limit of safety will have been passed when a side-thrust of 20,000 pounds has been attained with a weight of 35,000 pounds on a driving-wheel, and this fact has been sustained by practical tests.

Because the rib, or other projection on the under side of the tie-plate, sinks under the weight into the tie, the lateral motion of the rail is resisted before the spikes become loosened. On a test with a wheel-load of 35,000 pounds the rail turned over, and the tie-plate was forced into the tie, crushing and splitting it. In practice, however, there is not a wheel over each tie, and with ties spaced 21 inches apart under a locomotive with driving-wheels six feet in diameter, the wheel is supported by three ties. The crushing effect would not, therefore, be as severe as in the experimental tests, and, with seven spikes to resist the side-thrust, the resistance to overturning is 35,000 pounds instead of 10,000 pounds. The thrust in practice, however, is produced by quickly applied loads or shocks, while, in the experimental tests, the thrust was effected by steady pressure. Therefore, when a rail is subjected to side-thrust from train-momentum with a 35,000-pound wheel-load, the factor of safety does not exceed two for the 100-pound rail with standard tie-plates; whereas the theoretical factor of safety is placed at ten for iron or steel subjected to sudden shock from a live load.[1]

[1] For various wheel-loads, the side-thrusts are as follows:

Wheel-loads, Lbs.	Side-thrust, Lbs.	Percentage
15,000	17,500	116.5
20,000	20,000	100.0
25,000	22,500	90.0
30,000	25,000	83.5
35,000	27,500	78.5
40,000	30,000	75.0

As the weight of the locomotive increases, the side-thrust necessary to overturn the rail becomes a decreasing percentage of the wheel-load.

"The Actual Service of the Track Spike and Tie-plate," W. D. Wood. Railway Age Gazette, February 20, 1914. See also Appendix V, Table X.

The underlying fact in track-deterioration is that the dynamic action of the train exceeds the static resistance in the track. It is a matter of momentum. The effects vary in intensity with the load and the speed. The force or momentum, accumulated in a train of twelve heavy passenger cars drawn by a ponderous locomotive at sixty miles an hour, has been estimated at 224,000,000 foot-pounds, but this applies to movement in a horizontal direction. It is surprising that any track, however well constructed, can fulfill the conflicting requirements for rigidity and for elasticity under such conditions. It may be remarked, however, that rigidity of track is a requirement for effective resistance to longitudinal or lateral movement or displacement, while elasticity is a requirement for a perfect reaction to the wave of deflection accompanying a moving train. The track should possess resiliency, acting with a cushioning effect for absorbing the shock of impact. The slight yielding under the moving weight of a fast train is a protective agency, offering the graduated resistance of a spring, not that of an anvil.

As the track thus yields under the moving train, the foremost wheels are continually operating against the elevation caused by the preceding wave of deflection, which induces a gradual movement of the track in that direction. This movement is counteracted on a single-track line by a similar movement in the opposite direction. But there is a resulting balance in the direction of the heavier traffic which effects a positive movement in that direction. This effect is merged at curves in the line into a slight distortion of the curvature. On long tangents, including grades descending in the direction of the movement, it may result in "buckling" the track, and its extent is much increased in very hot weather by the effect of expansion at the closed joints. Although the track may be heavily ballasted, the joint-ties will move with the rails, and even in a double-spiked track, the rails will slip over the intermediate ties, leaving a shaving of metal behind each spike. This "creeping" of the rails becomes far more serious on a double-track line, with the traffic always in one direction on each track, and is facilitated by the disconnection of joints at the switches. British track-construction yields more readily in this respect; as the bull-head rail is not spiked directly to the sleepers but is held in position by wooden keys. In a stretch of 352 yards, there was an aggregate creep of 56 inches in the course of two years; the rails having been pulled back fourteen times during that period. The use of joint-fastenings as road-anchors, by slotting them for spikes, imposes an additional burden on the joint, which is the weakest point in the track-structure, while the elimination of slots and punch-holes adds to the strength of the fastenings. Joint-ties are not then slewed out of place, angle-bars are not stripped by the slotting nor is there an extra strain upon the joint-bolts. Separate road-anchors should be used in sufficient number to resist creeping, without relying on joint-fastenings.

Problems of Curvature

The momentum of a train develops centrifugal force around curves, varying with the speed and weight of the train.[1] The consequent shock to a train upon entering a curve at a high rate of speed is lessened by the intervention of a transition-curve of greater radius at the points where a tangent is merged into the principal curve. This effect of curve-resistance is negligible in a modern passenger-train at a speed of 18 miles an hour on a ten-degree curve, and at 13 miles an hour on a curve of twenty degrees.

The centrifugal force induces a tendency for the wheel-flange to mount the outer rail, which is counterbalanced by the super-elevation of that rail. Definite formulas have been devised for determining this super-elevation, but the conditions vary so widely with the speed of the train, that it is rather an empiric than a mathematical problem. In practice, the maximum super-elevation is eight inches. The effect of the train-momentum is perceived in the distortion of the curve, which may be counteracted by laying a check-rail or guard-rail, firmly fixed at a proper distance from the gauge-side of the inner rail; or by rail-braces against the outer rail. The effect of obliquity of traction at the couplers is now considered as unimportant.

The resistance in a curve to the passage of a train is independent of the momentum or the length of a train, and is a reaction to the slipping of the loaded wheels. The supposed advantage of coning the wheel-tread soon disappears as the tread wears away. The greater length comparatively of the outer rail compels a constant readjustment of the progress of the wheels on the same axle, that is only made possible by the occasional slipping of the outer wheel, as its flange strikes against the rail. The

[1] Centrifugal force in pounds per ton of 2000 pounds on various curves at various speeds. A. M. Wellington. "Railway Location," Ed. 1914, p. 270.

Speed, Miles per Hour	Degree of Curvature				
	1	5	10	15	20
10	2.33	11.67	23.35	35.02	46.70
20	9.34	46.70	93.39	140.09	186.78
30	21.01	105.07	210.13	315.20	420.26
40	37.36	186.78	373.57		
50	58.37	291.85			
60	84.05	420.26			
70	114.40				
80	149.43				
90	189.12				
100	233.48				

The computation ends at an assumed maximum limit of speed for safety; that is, when the centrifugal force equals one-fourth of the weight.

momentum of the train is transmitted to the wheels from the bodies of the several units in the train through the center-pins and side-bearings of the trucks, somewhat modified by the action of the springs.

The rigid wheel-base of the truck is the principal factor in the effects produced by the slipping of the wheels. There is a normal play of $\frac{3}{8}$ to $\frac{3}{4}$ of an inch between the wheel-gauge and the track-gauge, which affords some ease by the lateral slipping of the forward truck wheels, permitting a rigid wheel-base of 12 feet on curves up to 3 degrees, and a wheel-base of 5 feet on a 17-degree curve. The longitudinal slipping occurs irregularly either with the forward or the rear pair of wheels, and its effect is exhibited in the wear of the rail-heads around a curve from the flange-friction. The curve resistance is directly as the degree of curvature, with corresponding rail-wear. The sharpest curves on the main tracks of the Trunk Lines are as follows: Pennsylvania Railroad, 8 degrees; Baltimore & Ohio Railroad, $9\frac{1}{2}$ degrees; Erie Railroad, 10 degrees. There is no curvature of as much as eight degrees on the main tracks of the New York Central Railroad.

Switches, Frogs and Crossings

The effect of train-momentum is especially severe where the continuity of the rails is broken at switches, frogs and crossings. At these points, the track should be maintained in first-class condition, to insure the passage of trains at high speed. With the original "stub-switch" this was impracticable, as both switch-rails break connection completely in the running-track. Their movable ends are only secure while the switch-lever holds them against one lip of the chair in which they move laterally; and their other parts are kept in position solely by the tie-bars which hold them to gauge. Consequently, the stub-switch has been replaced by the "split-switch" which, if carefully maintained, is safe for the passage of trains at any speed.

In the split-switch, the position of the switch is reversed, with its fixed ends toward the stock-rail leading to the frog. The running-track rail next to the siding leads without a break into the siding; the continuity of the main line being preserved or broken by a movable rail on that side in the running-track. The opposite rail in the main line is also unbroken. The switch-rail on that side is connected by tie-bars with the movable end of the rail in the running-track and, as they are moved laterally, the entrance into the siding is opened or closed. The movable end of each of these "split-rails" is planed to a thin vertical edge, which fits into the web of the permanent rail for protection and leaves the flange-way free along one or the other of the permanent rails, accordingly as the switch is moved. By the interposition of a stiff, coiled spring in the pull-rod of the switch-lever, a train running from the fixed end of the switch may force its way either from the main line or from the siding while the switch is set for the other track, without the intervention of a switchman. A switch facing the direction of a train on the running track, is termed a "facing-switch"; and in the opposite direction, a "trailing-switch."

Where two sidings diverge to opposite sides of a running-track at the same point, a "three-throw" switch is used. The three-throw switch is a double switch with the outer rail on each side permanently connected with the siding and the inner split-rails moving together in opening either siding. These rails intersect at a crotch-frog in the center line of the running-track. As the three-throw switch, like the stub-switch, breaks both rails of the running track at the same point, it is rarely used in the main line. Where double-sidings are necessary, it is preferable to place one switch ahead of the other.

Bumping-posts are necessary where a stub-track ends on a bank or trestle, or against a wall or fence. Where the end is clear and the ground is level, less damage is done by careless switching if the cars drop off the ends of the rails. The levers to ground-throw switches should throw parallel with the track and should lock automatically. All yard-switches should be numbered.

Where two running-rails cross, provision must be made for the passage of wheels on either line by a "flange-way."[1] The angles at the intersection are preserved by planing the two rails in one direction to an acute angle, firmly bolted together, and by bending the rails outward in the opposing angle as "wing-rails," for bearing the wheel over the gap at the intersection. This intersection is known as a "frog," from a fancied resemblance to the frog in a horse's hoof. The wheels are prevented from taking a wrong direction at this point by guard-rails fixed against the opposite continuous rail. Many plans have been devised for diminishing the exceptional wear at the gap thus formed in the track. In some of them, the wing-rails are held closely to the point of the frog by springs which are forced open by the passage of a wheel on one side or the other. In other cases, a riser is placed in the throat of the frog which relieves the wear of the point by taking the weight from the edge of the wheel-flange. The objection to having so many parts connected by bolts and chairs, at a point where solidity of structure is all important, is obviated by consolidating them in a steel casting specially suited to the angle of intersection.

The Wharton switch, an American invention, is operated without a break in the main track, either for switch or frog. When out of position, it is entirely clear of the line but when a train is to take the siding, it is moved up laterally so that the switch rails fit closely to the running-rails and gradually lift the wheels; one wheel rising on the tread until it clears the running rail at the point of contact and the other rising on the edge of

[1] In early track-construction, the flange-way at this intersection was provided by a movable piece of rail, pivoted in the track like a switch-rail, which could be thrown over to the siding-rail by a separate lever.

the flange until it is carried above the same rail at the point of intersection. This switch is well suited for entering sidings that are but little used, and at low speeds.

"Cross-overs" between running-tracks are properly laid with a trailing-switch in each track, and should have longer leads and frogs with smaller angles than for siding-connections. The length of the leads from switch to switch varies with the spacing of the running-tracks and the angle of the frogs. The minimum length is 122 feet 6 inches for a No. 6 frog (9° 31′ 38″) and 11 feet between track-centers. The maximum length is 381 feet 3 inches for a No. 15 frog (3° 49′ 06″) and 16 feet between centers.

The crossing of one track by another is effected by a combination of four frogs in opposite pairs, two at an acute angle and two at an obtuse angle, or all at 90° if the crossing is rectangular. These crossings become complicated where double-tracks cross, and still more when they include connections between main lines by "slip-switches." [1] Such crossings require specially constructed combinations of rails and castings.

A crossing at right-angles is objectionable because the width required for the flange-way in both lines of rails leaves little bearing for the wheel tread on the wing-rail and throws additional stress on the frog-points, which should, therefore, be made of manganese-steel and be removable for replacement. The standard width of flange-way as established by the American Railway Association is 1¾ inches between the main rail and the guard-rail and through the throat of the frog, measured at the gauge-line. All guard-rails and frogs should be filled in to the head of the rail with an iron block to prevent the feet of employees from being caught in them in the face of an approaching train.

The dimensions of frogs are indicated by angular measurements and they are classified by standards to facilitate their manufacture as stock material. In Great Britain, this classification is determined by the relation of the altitude to the base of the isosceles triangle thus formed, and varies from 1 to 4 to 1 to 12. The obtuse angle at a crossing is limited by the Board of Trade to 1 to 8. In the United States, frogs are classified by numbers. The number refers to the relation of the length of the frog to the distance between the gauge-lines at its heel; the length being the distance in feet from the theoretical point of intersection of the gauge-lines to the point at which they are one foot apart. The numbers range from No. 4 with an angle of 14° 15′ 00″ to No. 24 with an angle of 2° 23′ 13″.[2] The No. 8 frog is ordinarily used in yards and No. 10 in running-tracks.

[1] A slip-switch is a switch-connection inserted in a crossing in such a manner as to provide connection between the two lines of rails. A double-slip provides for communication in either direction from either track.

[2] For dimensions of standard frogs and switches, with length of leads and switch-rails, see "Freight Terminals," J. A. Droege, 1912, p. 47. For length of cross-overs, *ibid.*, p. 50.

Maintenance of Way

Notwithstanding the improvement in processes of manufacture and in the designing of details, the standard track is still unsatisfactory with respect to its stability and endurance under heavy traffic. Like the macadamized road, its surface suffers continual deterioration from rolling-friction. But the macadamized road has only to offer a dense and coherent resistance to wheel-treads whose loads are transmitted normally to the substructure without internal disturbance. In this respect, it somewhat resembled the primitive stringer-track, in which the strap-rail was only intended to resist wheel-wear. This relation disappeared when the rail was required to act also as a girder. The incessant disturbance thus occasioned to the structure of the track, by the passage of trains, is only counteracted by an incessant reconstruction of it in every part. The fastenings are to be tightened up; the ties are disturbed in their beds to restore the alignment; there is another disturbance to renew the defective ties and deficient ballast and, at periodic intervals, a general upheaval with the rail-replacement. In addition to the labor required to keep the track in efficient condition, the cost of rehandling stone-ballast, of repairs to fencing and road-crossings, of keeping down the undergrowth on the right-of-way and of the general policing of the roadway, is no small part of the expense incurred in the Roadway Department. The extent to which the traffic affects the relative deterioration of the principal elements in track-construction may be inferred from the distribution of the items of cost in roadway maintenance, derived from the experience on a number of railroads in the United States, for periods of two to eight years and covering 10,127 miles of main line and 3192 miles of branch-lines, with an average daily traffic ranging from 3 to 11 passenger-trains and from 7 to 44 freight-trains.[1]

Efficiency in track-maintenance has been increased by the use of mechanical appliances, of track-jacks, ditching machines, tamping machines,

[1] Distribution of Items of Cost of Roadway Maintenance

	Per Cent.	Per Cent.
Rail renewals		28.9
Track and Roadbed		
Ties	11.7	
Earthwork and Ballast	12.6	
Surfacing Track	24.6	
Switches, Frogs and Sidings	5.4	54.3
Structures		
Bridges	8.5	
Buildings	8.3	16.8

"Railway Location," Wellington, p. 120.

unloading-plows for distributing ballast, steam-shovels and steam-cranes.[1] The gasoline-engine is being gradually utilized to diminish or to reinforce manual labor in track-maintenance. The gasoline motor-car may well replace the lever-car, which was itself a relief to the gangs that worked their way to and from their daily tasks on pole-cars. Gasoline weeding and mowing machines have also been devised.

An army of men is daily employed in tamping track with primitive implements, and here seems to be an opportunity for using mechanical appliances to advantage. An electrically operated machine weighing 1900 pounds tamped a mile of track in fifteen days at a cost of $157, against hand-tamping in 26 days at a cost of $299. A pneumatic machine weighing 37 pounds (consuming 19 cubic feet of free air at 70 pounds' pressure), with several hundred feet of ¾-inch hose, is coupled to a gasoline-engine of 12 horse-power. Two of these machines, the entire outfit weighing 2495 pounds, and operated at 70 pounds' pressure by 21 men, tamped a mile of track at a cost of $196, against hand-tamping at a cost of $282. The average settlement after six months was 0.33 foot in the machine-tamped track and 0.67 foot in that which was tamped by hand.[2]

The substitution of machinery for manual labor has also been applied on work-trains. The outfit consisted of a light locomotive, two dump-cars of 20 cubic yards' capacity each, a power-ditcher, a spreader and a crew of eight men. The ditching-machine was a small revolving steam-shovel with a half-yard bucket, mounted on a portable track on a flat car between the dump-cars. The machine had a hose connected to the tender and supplied its own tanks while the train was in motion. The loads were dumped clear of the ballast by compressed air from the locomotive. The cars were loaded from the ditches in about half an hour and, with a haul of one to four minutes, made ten to twenty trips a day, handling more material than a train of fifteen flat cars of ten-yards' capacity with twelve men. No time was lost in shifting a ditching-plow and plow-cable at each trip. The train requires only a short siding and is conveniently unloaded for filling bridges or widening banks.[3]

The maintenance of track will doubtless be still further facilitated by such appliances, but, as long as the track is required to resist the wave of deflection by a combination of elasticity and rigidity, so long will the never-ending processes continue of structural disintegration and restoration. When we consider the stresses to which a track is subjected and the disastrous consequences that may result from a failure of a single fastening, or from neglect in some minor respect, it is not surprising that catastrophes do occasionally occur. In ten years, including 1915, the derailments reported by the Interstate Commerce Commission as due to defec-

[1] Upon the Lehigh Valley Railroad, with four locomotive-cranes, 4.07 miles of track were relaid with 100-pound rails in six hours; the old rails being thrown out at the same time.

[2] Engineering News, March 11, 1916. [3] *Ibid.*

tive roadway have averaged 1477 per annum. In 1915, they numbered 1507, or about four or five a day, distributed over some 264,000 miles of line.[1]

Gauge of Track

The gauge of a railroad affects its economic efficiency as to the stability of the vehicle in use upon it or as to the cost of construction. Neither of these matters, however, was considered in the establishment of the "standard" gauge now predominant in the railway mileage of the world. This standard-gauge originated when the flange was put upon the tires of the colliery wagons to enable them to run upon an "edge-rail." The resulting relation between the wheel-gauge and the track-gauge happened to be 4 feet 8½ inches. This relation accompanied the development of the colliery tramway into the commercial railway in England, whence it extended to the continent of Europe, to the United States and elsewhere with the introduction of the English locomotive.

The first departure from the standard-gauge was with the gauge of the Charleston & Hamburg Railroad in South Carolina, which, in 1830, was fixed at five feet by its engineer, Horatio F. Allen.[2] As the standard gauge extended from England to the continent of Europe, so did the five-foot gauge extend from Charleston, northward to Wilmington, N. C., along the coast, along the eastern slope of the Blue Ridge to Richmond and Washington, and to the Ohio and the Mississippi rivers.

An instance of the fortuitous circumstances under which the gauge of track has been established by law, was shown in the establishment of a standard gauge in the State of Ohio. The first railroad in that State was begun in 1835 by the Mad River & Lake Erie Railroad Company, now merged with the New York Central Lines. In 1837, the president of that company witnessed the trial trip of the first locomotive built by Rogers,

[1] Derailments Due to Defective Roadway During Ten Years, Including 1915

Causes	Annual Average Ten Years	In 1915
Broken rail	274	272
Spread rail	182	90
Soft track	218	354
Bad ties	45	61
Sun-kink	24	32
Irregular track	326	415
Miscellaneous defects	408	283
Total	1477	1507

[2] Allen went to England in 1827 to purchase rails for the Delaware & Hudson Coal & Canal Company's railroad and had then the opportunity to study railway construction in its earlier stages.

Ketchum & Grosvenor in Paterson, N. J., and was so much pleased with the sound of the whistle, which was then a novelty, that he bought the locomotive on the spot, and laid his track to suit its gauge, which happened to be 4 feet 10 inches. At the next session of the legislature, that gauge was established by statute as the standard-gauge in Ohio.[1]

The next departure from the present standard-gauge originated with the construction of the Erie Railroad begun in 1839 on a six-foot gauge, in fulfillment of a provision in its charter forbidding a connection with railroads leading to other seaports than New York. The Erie Railroad was the parent of a broad-gauge system extending westward to Cleveland, to Cincinnati and to Chicago; and, in 1864, to St. Louis, making it the first line of uniform gauge to connect the Atlantic seacoast with the Mississippi River. Up to that time, the diversity of gauges in the rapidly extending railway system of the United States was compelling frequent transfers, with serious inconvenience to travelers and delay to freight-shipments.

In 1852, connection was established from Buffalo along the southern shore of Lake Erie by the completion of the Painesville, Ashtabula & Geneva Railroad. Continuous train-service was, however, broken at the borders of Pennsylvania and the adjacent states of New York and Ohio by an intervening link of twenty miles, which had been built on the six-foot gauge as a connection of the Erie Railroad. The traffic between Buffalo and Cleveland was, however, of so much greater value that, to secure it in competition with the steamers on Lake Erie, preparations were made to change this line in Pennsylvania to standard-gauge. In anticipation of the impending loss of business by the hotels and other interests in the city of Erie, which were profiting by the transfer at that point, a mob, led by the mayor, tore up six miles of line. Five attempts to relay the track were resisted by violence and only after a lapse of two months was the "Erie War" terminated by the proclamation of martial law.

A similar "Battle of the Gauges" took place in Great Britain in consequence of the adoption of the seven-foot gauge in the construction of the Great Western Railway, which was opened from London to Bristol in 1835, and which led to a mileage of 1456 miles of that gauge. Other lines had been built on a five-foot gauge and the consequent inconvenience to traffic aroused an agitation in favor of a uniform gauge. This battle was, however, fought in Parliamentary committees by extravagantly-feed lawyers and was only terminated by the appointment, in 1849, of a Royal Commission to investigate the matter. The resistance to innovation was too strong to be overcome. In 1872, a third rail was laid on the broad-gauge lines to admit of the passage of standard-gauge equipment, but it was not until 1892 that the broad-gauge lines were entirely changed. As a result of this contest, the gauge of the Irish lines was established at 5 feet 3 inches, that

[1] "When Railroads were New," C. F. Carter, p. 222.

being an alleged compromise between the standard-gauge and the broad-gauge.

There was yet another gauge that gained notoriety in the United States about 1870, the "narrow-gauge" of three feet. It had nothing to recommend it except its low cost, which was largely due to cheap construction and equipment. It gradually disappeared as the lines of that gauge were absorbed by standard-gauge lines or were reconstructed. At the present time, there are probably not more than 1600 miles of line of three-foot gauge remaining in this country, otherwise than on industrial lines.

While the narrow-gauge was in vogue, several plans were devised for exchange of freight-traffic with standard-gauge lines without breaking bulk. Of these, the drop-pit was most in use. It was not applicable to the exchange of passenger-car bodies of standard-gauge. It worked fairly well, however, with lines of five-foot gauge, especially with Pullman sleepers, as their trucks were built to standards and could readily be interchanged. Transfers of trucks were usually made within fifteen minutes, and with little inconvenience to the occupants.

In the Act of Congress, approved July 1, 1862, chartering the several Pacific Railroad companies, it was provided, "That the track upon the entire line of railroad and branches shall be of uniform width to be determined by the President of the United States, so that, when completed, cars can be run from the Missouri River to the Pacific Coast." By a further Act, approved March 3, 1863, it was established, "that the gauge of the Pacific Railroad and its branches throughout their whole extent, from the Pacific Coast to the Missouri River, shall be, and hereby is, established at four feet eight and one-half inches." This action of Congress sealed the fate of the broad-gauge on every trunk line, from the Atlantic Coast to the Missouri River, which aspired to transcontinental traffic. By 1882, that gauge had yielded on the Erie Railroad and its connections to the demands for uninterrupted intercommunication.

Change of Gauge on Southern Railroads

The increasing importance of the traffic crossing the Potomac and the Ohio rivers constrained the principal north and south lines of five-foot gauge to take similar action. The organization for a change to standard-gauge on the entire Southern system of nearly 15,000 miles was deputed to a committee of general managers, which appointed sub-committees of officials representing each operating department to recommend, as to details, the course to be pursued in effecting the change of gauge. For some two years this matter was in hand and preparations for making the changes in motive power, rolling stock and roadway were made in accordance with the committees' recommendations.

New locomotives were fitted with dished driving-wheel centers, so that the change could be made by merely reversing the wheels on the axles.

New truck-wheels and axles under all equipment were fitted with a wheel-seat of sufficient length for each wheel to be pressed back one-half of the difference in gauge, or $1\frac{3}{4}$ inches, this space being filled in by a collar next to the journal-box. A railroad-track is lined continuously along the same side, known as the "line side," and the other side, or the "gauge side," is brought into line by the track-gauge. In preparing for the change, the line-side was not disturbed, but inside spikes were partially driven on the gauge-side at the prescribed distance to suit the standard-gauge. Spare switches of that gauge were distributed at all sidings connected with the main line. Advantage was taken of the opportunity to increase the equipment by additional locomotives and cars of standard-gauge, parked at convenient points on long stretches of sidings of standard-gauge, which, in many instances, were afterwards utilized as passing-sidings or as sections of second track. The transportation officials collaborated in adopting provisions for running the five-foot gauge equipment off the line on to temporary sidings as the change of gauge progressed, and many sidings were changed in advance. An army of extra laborers was recruited for the special occasion, distributed in gangs with men of the regular track-forces, and all were provided with necessary tools and food-rations.

The date for beginning the general change was fixed for May 31, 1886, and the day before that date every alternate inside spike was drawn from the ties on the gauge-side of the track. Upon the completion of these preparations, word was passed by telegraph throughout the five-foot gauge system. As the order was extended to the roadway department, the gangs distributed along the line drew the remaining inside spikes, lifted the rails on that side out of the outside spikes, still connected together by the fish-plates, and threw them over with crow-bars against the inside spikes previously set to standard-gauge. These spikes were then driven home, the switches and frogs on the main line were readjusted and each gang made its report to headquarters, where the general manager and his staff remained, through the day and night, recording the progress of the work on maps of the line, and ordering changes of forces to points where the work was being delayed.

The change was effected with such promptness that, on the morning of June 1, 1886, the Florida Express ran over the changed line from Wilmington, N. C., to Jacksonville, Fla., a distance of 498 miles, at a speed of nearly 50 miles an hour, preceded by pilot-locomotives, and arrived at Jacksonville on time. On the Charleston & Savannah Railroad, 128.7 miles of main line and sidings were changed in six to eight hours by 359 men, distributed in 25 gangs. On the Louisville & Nashville Railroad, 1806 miles of main line and sidings were changed in a single day by a force of 8763 men.

Upon the completion of this remarkable undertaking, the standard-gauge became virtually universal in the United States, and was made so formally by a resolution of the American Railway Association, adopted April 7, 1897, as follows: "That 4 feet 8½ inches shall, hereafter, be the standard gauge of all tracks owned by the railroad companies forming this Association. This gauge shall be the distance between the heads of the rails at right angles thereto, at a point five-eighths of an inch below the top of the rail." There is still a considerable mileage of 4 feet 9 inches gauge, which slight difference does not interfere with through-train service.

Different Standards of Gauge

Although the standard-gauge is, by far, the more general in North America, yet in Great Britain and in most of the countries of Continental Europe, there are still more than twenty different gauges. In Great Britain and Ireland alone there are twelve gauges.[1] Those wider than "standard-gauge," or of "broad-gauge," range from 5 feet in Russia to 5 feet 3 inches in Ireland and South America, 5 feet 5⅔ inches in Spain and Portugal, and 5 feet 6 inches in British India. "Narrow-gauges" range from 1 foot 11½ inches to 3 feet 6 inches. The narrow-gauge lines built with British capital are generally 3 feet 6 inches, or of the meter-gauge where capital has been obtained in Continental Europe.

In Australia, as in the United States, the differences of gauge have caused dissatisfaction. Out of 18,979 miles of line in 1914, 18,035 miles were owned by the several states and, of this mileage, 10,217 miles were not of standard-gauge. In Queensland and South Australia, there were 6066 miles of 3 feet 6 inches gauge and, in Victoria, 3525 miles of 5 feet 3 inches gauge. Since the unification of government in Australia, uniformity of gauge has become a political issue.

In South America, a uniform gauge is a commercial as well as a political question. In Brazil, the narrow-gauges predominate, though there is a considerable mileage of standard- and of broad-gauge lines. The standard-gauge prevails in Uruguay and in Paraguay, and in the adjacent provinces of the Argentine Republic, though in that country important territory is occupied by other gauges. In Chile, there are seven different gauges on 6738 miles of line. In Bolivia, the meter-gauge prevails, though on an important line, the Antofagasta Railway, it is 2 feet 6 inches. Peru is committed to the standard-gauge, but in the states northward as far as Mexico, the railways are, for the most part, narrow-gauge, with the exception of the Panama Railroad, which is five-foot gauge.

In South Africa, the gauge is 3 feet 6 inches, and this will probably be the gauge of the projected "Cape-to-Cairo" line, as 1500 miles of line in Egyptian Sudan is also of that gauge. For the unification of the line to the Mediterranean, it will be necessary to change the standard-gauge of the extension through Lower Egypt.

[1] See Appendix V, Table XI.

The five-foot gauge was introduced by Colonel Whistler into Russia from the United States, with the construction of the line from Petrograd to Moscow, opened in 1851, and has become the established gauge throughout the empire from political and military considerations. Through-train service is maintained with Western Europe by change of trucks.

In British India, the mileage of 33,000 miles is nearly divided between the 5 feet 6 inches and the meter-gauge. In New Zealand, Tasmania, Japan and Newfoundland, the gauge is 3 feet 6 inches. In Belgium, in 1910, there was a meter-gauge of 2371 miles on 148 lines of "light railway," of which one-half was laid on public highways.[1]

Turnouts and Sidings

The location and arrangement of sidings becomes an important matter with increasing traffic. In early railroad operation in the United States, the single siding at a way-station was used indiscriminately for standing cars and for passing trains. When there were cars in the siding, trains had to "see-saw," with the standing cars coupled ahead of one of the locomotives, and with consequent delay. Often these "turn-outs" were "blind sidings," with but one switch, and it required considerable cleverness on the part of the trainmen to pass trains that were too long for the sidings. Blind sidings are now rarely used except as a temporary expedient for work-trains. With sidings at way-stations, where the station-building is used for both passenger and freight service, it is preferable for the building to stand between the two lines, so as to leave the way unobstructed between the trains and the station-building. The passing-siding at a way-station should be on the opposite side of the line. Passing-sidings, however, should not be located where their use might incommode the station-service or block a road-crossing.

The clearance-posts at sidings are usually placed at the side of the track and painted white to make them distinct. A preferable plan is to

[1] Proportion of Mileage of Different Gauges

	Standard-gauge	Narrower Gauges	Broader Gauges
	Per Cent.	Per Cent.	Per Cent.
Europe	71	7	22
North America	98	1.99	0.01
South America	14	50	36
Asia	7	50	43
Africa	17	83	
Australasia	20	58	22
The World	71	14.5	14.5

Railroad Gazette, International Issue, July 8, 1910. See also Appendix I, Table I.

use short stone-pillars, placed in the middle of the siding-track with the tops whitened and made even with the surface of the ties. When so placed, men can not stumble over them, and it can be seen at once whether cars on the siding are clear of the main line.

On single-track roads, as the freight-traffic increases, there will occur a normal congestion of meeting and passing trains within certain limits, due to the exigencies of the service. Wherever these conditions prevail, passing-sidings should be specially arranged for relief. The spacing of these sidings should be carefully considered with reference to the points on a division at which there is a congestion of train-movements. A location should be selected away from any way-station, preferably at a summit and free from road-crossings. At this point, there should be a siding on each side of the main line, long enough for at least two freight-trains with the switches "lapped"; that is, so arranged that the entrance-switch of each right-hand siding could be reached by an approaching train in advance of the switch by which a train from the opposite direction would leave the siding on the opposite side. Such an arrangement lessens the probability of collisions at passing-points. Water-cranes should be so placed that, when necessary, the tenders can be filled while the trains are on the sidings; and, in connection with the signal-cabin, there should be a comfortable room where the trainmen can receive their orders.[1]

Industrial sidings must be located to suit the industries which they are to serve, but they should be entered from a siding parallel with the main line, and on this siding trains should stand while at work there, in order to keep the running-tracks unobstructed. "Cross-overs" in double-track should be laid with trailing-switches in each track, so that they can only be entered in reverse direction to the usual train-movement, in order to avoid facing-switches in the running-tracks and the possibility of accident from an "open" switch.

With increasing traffic, passing-sidings cannot afford the necessary relief to a single-track road. Further relief may be found by extending passing-sidings into running-sidings, or virtually stretches of second track, but the line would still be operated under single-track conditions. The only permanent remedy is the construction of sections of second track long enough for operation as double-track. Just when the time may be said to have arrived for that expenditure, in the increasing traffic of a single-track road, is a debatable question, which is generally deferred until the resulting congestion becomes unbearable. Relief is meanwhile sought by bunching the freight-trains in sections. In this way, delay to passenger-trains may be prevented at passing-points, but the freight-service is thereby seriously affected, while a hot box or a broken axle may throw the entire train-movement out of joint for hours at a time.

[1] See "Economics of Railway Operations," Byers, p. 636.

Double-track in the United States and Great Britain

There has been very little original construction of double-track line in the United States. The road from Philadelphia to Columbia, 82 miles long, was opened in April, 1834, with a single track and a second track was completed in the following October. The second track of the Pennsylvania Railroad Company was completed across the state in 1877, and that company now has a four-track line from New York to Pittsburgh. The New York Central line is four-tracked between Albany and Buffalo, and the Harlem line, which parallels the main line, virtually constitutes a four-track line between New York and Albany. The West Shore Railroad, in connection with the road from Syracuse through Geneva and Batavia to Buffalo, also provides an auxiliary route between New York and Buffalo.

In 1908, on 230,000 miles of railroad in the United States, but eight per cent. was double-tracked. In 1914, on 256,000 miles, the second-track mileage had been increased to ten per cent. The third and the fourth track mileage had been increased in the same period from 3490 to 4767 miles. There has been a remarkable development of yard tracks and sidings which, in 1908, amounted to 79,453 miles and, in 1914, to 98,285 miles; an increase of 18,832 miles, or 23.7 per cent. while the line-mileage increased but 11.3 per cent. during the same period. In 1914, the mileage of yard tracks and sidings amounted to 38 per cent. of the line-mileage and to 25 per cent. of the total track-mileage. In the Eastern Territorial District, with but 25.3 per cent. of the total line-mileage, the yard and siding mileage constituted 40.8 per cent. of the total mileage of that kind in the whole country. In the several territorial districts, the proportion of yard and siding mileage to that of running-tracks was, in the Eastern District, 47 per cent.; in the Southern District, 21 per cent.; and in the Western District, 28 per cent.[1] Double-track construction was common in England from the inception of railway development, as the early lines were intended to provide for a heavy coal-traffic. Yet a large part of the railway system of Great Britain and Ireland is still single-track. The proportion to line-mileage in 1910 was, in England and Wales, 38 per cent.; in Scotland, 58 per cent.; in Ireland, 80 per cent.

The statistics of yard tracks and sidings are indicative of the relative importance of the manufacturing interests in the several countries forming the United Kingdom. In this respect, it is of interest to compare the trackage in the Eastern Traffic District in the United States in 1914 with that in England and Wales in 1910, as a measure of the railway facilities provided in each region for commercial intercourse. Though the total trackage per square mile in the Eastern District is only about one-half of that in England and Wales, it is double in proportion to the population.[2]

[1] For details of Track Mileage in the United States, see Appendix V, Tables XII to XIV.

[2] See Appendix V, Tables XV and XVI.

Electric Traction Requirements. Third Rail and Overhead Systems

The details of track-construction have been somewhat affected where electricity has been substituted for steam as a tractive force. The direct connection of the motors with the driving-axles of the tractors, resulted in an increase of weight not spring-borne which aggravated the hammering upon the rail-ends. The accompanying lowering of the center of gravity caused a greater horizontal stress upon the rails that increased the difficulty of keeping the track in line. The passage of a single train at high speed sometimes undid a whole day's work of a track-gang. These defects were somewhat remedied by placing a four-wheel truck at each end of the tractor, and by raising the motors above the springs and by returning to the intervention of connecting-rods and cranks for transferring the rotary motion to the driving-axles.

With the direct-current system, the current is transmitted through an insulated "third rail," placed upon the ties along the outside of one of the running-rails. This rail is generally of the inverted "T" pattern, though on the Pennsylvania Railroad a rail-conductor has been adopted of a special section and composition weighing 150 pounds per yard, with conducting activity equivalent to that of 1.9 square inches of copper. The third rail is usually protected from accidental contact by a wooden covering or "roof," except in some cases on branch-lines within a fenced right-of-way. The current is either transmitted to the motors by contact with the upper surface of the rail or, as on the New York Central Railroad, the contact-shoe comes in contact with the lower surface of the feed-rail, and the rail is so protected that a person could not come in contact with it unless he knelt down and put his hand beneath the roof. The rail is also better protected from snow or sleet.[1]

To prevent encroachment upon the space necessary for operation, and to facilitate the interchange of equipment, the American Railway Association has approved specifications for standard location and clearance in third-rail construction which prescribe that any device attached to the permanent way may not project more than "2½ inches above the top of the track-rail in the space from a point 19¾ inches from the gauge-line to a point 6 inches above the gauge-line." The clearance in all equipment had also to be carefully defined so that no part should come within a space

[1] With top-contact, the third rail rests upon insulators bolted to the ties. It is gauged 26 inches from the gauge-line of the running-rail, and its upper surface is 2½ inches higher than the top of that rail. The top of the roof is about 6 inches higher than the top of the running-rail.

With under-contact, the third rail is insulated in brackets bolted to the ties, leaving its under surface free. It is gauged 27 inches from the running-rail and its under surface is 2¾ inches higher than the top of that rail. The total height is 8½ inches higher than the top of the running-rail. The third-rail system requires accurate alignment.

6 inches above the top of the rail and 18¼ inches outside the gauge-line, which includes an allowance of 2 inches for horizontal variation and 4 inches for vertical variation due to wear of journals and brasses, for compression of springs and for variations in construction.

With the usual voltage of 600 volts, third-rail insulation is well maintained and, experimentally, with 1200 volts, though with greater difficulty under the usual conditions of track-maintenance. The freezing of snow and ice on the rail causes sparking by loss of contact. There has been some difficulty experienced from the third rail creeping on steep gradients, causing a fracture of the insulation. In yards and terminals, it is not practicable to secure continuous contact at switches between the rail and the motors. In such cases, auxiliary contact must be supplied, except with multiple-unit trains of more than two cars.

Electric traction with alternating current at high voltage is not practicable with the third rail as a conductor. Recourse is then had to the overhead system, as developed from the street-railroad trolley wire. In the operation of heavy trains at high speed, the conductor must be held in a uniform plane with sufficient flexibility, and compensation provided for the expansion and contraction due to changes of temperature; otherwise, there will be sparking with rapid wear of the collectors. This purpose is attained by the catenary suspension of an auxiliary steel wire, to which the copper wire is secured, by hangers, varying in length in each span to maintain the copper conductor in a uniform horizontal plane; danger from a fallen wire is also obviated. Deviations from the normal line of contact are admissible to a distance of thirty inches, horizontally and vertically. There is no disturbance from snow-drifts nor interference with track maintenance.[1]

The catenary system is attached by insulators to wires stretched across the track at intervals, and supported by iron posts. An auxiliary wire is sometimes interposed between the main suspension-line and the conducting-wire in order to diminish the undulations in operation, though experience has proven that the simple catenary is more reliable. The spans may extend to as much as 100 yards. At this distance, the lateral deviation from the middle of the track around a three-degree curve is not over 8½ inches, which is admissible with the pantograph or bow-collector. Greater deviation is corrected by wire-guys attached to posts beside the track.

On the New Haven line of four or more tracks, the overhead system is of a more expensive character than has been adopted elsewhere, on account of the very high voltage carried by the conducting-wire. Steel bridges

[1] For the safety of trainmen in giving lamp-signals from car-roofs, the wire should be not less than 24 feet above the rails in the open. The American Railway Association has recommended that, in freight-car construction, there should be a limit of 15½ feet from top of rail to brake-staff and wheel, to allow cars to pass over roads electrified by the overhead system.

span the tracks at intervals of one hundred yards, supporting a cable over each track upon porcelain insulators, from which the conducting wire is suspended. At intervals of two miles, the bridges are of heavier construction on concrete foundations. To these anchorage-bridges, the cables are attached by strain-insulators. The conducting-wire is attached to the suspension-wire every ten feet by triangular hangers of varying length, so adjusted that the line is maintained in a horizontal plane six inches below the middle of the catenary. At overhead-bridges, there is a specially constructed insulation of long porcelain corrugated tubes mounted on an iron pipe attached beneath the bridge, to protect the insulation from dirt and moisture. Both rails of all tracks are bonded with compressed-terminal bonds placed around the fish-plates. Where tracks diverge, a section-insulator is inserted in the conducting-wire and the diverging-wire is connected by a frog. Deflecting-wires are placed in the angle between the two conducting-wires, so arranged that the collecting-bows can not catch in the frogs. Two feed-wires constitute auxiliary lines to the main conductors, with which they are connected at each anchorage-bridge, through a circuit-breaker, by which different sections may be isolated in case of accident. The anchorage-bridges also carry shunt-transformers for operating the circuit-breakers, besides the lighting-circuit and the wires and conduits for operating the auxiliary-control circuit and the signal-apparatus. The semaphores are mounted beneath the bridges, which are provided with footways protected by hand-rails.

There has been a further development of this overhead system on the New York, Westchester & Boston Railway, which is a four-track subsidiary of the New Haven line. Here, the spacing of the spans around curves has been reduced to a minimum of two hundred feet. Where the curvature exceeds four degrees, pull-off poles of steel lattice-work, between the bridges, bring the conductors over the median line of the tracks. The four catenary cables are combined in a single-system at points 75 feet on each side of the bridges by cross-bars, or stretchers, of 3-inch "I"-beams. Intervening catenary cables are attached to these stretchers by porcelain insulators, and from each cable the copper conductor is suspended by hangers, 10 feet apart. Below each conductor is a steel contact-wire to take the wear of the pantograph-bows. It is held $1\frac{3}{4}$ inches from the conductor by clips placed midway between the catenary hangers.

On the Butte, Anaconda & Pacific Railway, which is operated with a direct current of 2400 volts, a 4–0 copper wire is suspended from a steel catenary on loop-hangers that permit the wire to ride up and down under pressure of the collector, independently of its catenary support. The collector has a 5-inch steel-tube roller, giving a service of nearly 30,000 miles at a maximum speed of 50 miles an hour. A similar overhead system is in use on the Chicago, Milwaukee & St. Paul Railway, with two wires, side by side, alternately suspended from the same catenary. As the collector passes beneath the clip of one hanger, the other wire is hanging free, and there is no tendency to sparking.

The danger to persons or property on the railroad right-of-way from the crossing of electric-light and power-transmission lines, and also the trouble to telegraph, telephone and signal wires occasioned from induction, has caused the American Railway Association to issue regulations on the subject covering twenty printed pages. The more important of them, as affecting roadway efficiency, are as follows:

I. That the poles or towers supporting a crossing-span shall not be less than 12 feet from the nearest rail on the main line nor less than 7 feet from sidings.

II. That the wires or cables shall not be less than 30 feet above the top of rail, at least 4 feet above bare telegraph, telephone or signal wires and 2 feet above insulated wires.

III. That lightning-protectors shall be thoroughly grounded at each crossing-support.

IV. That poles shall be properly guyed or braced.

The regulations also include specifications as to materials and methods of construction, and provisions as to tests and inspection.

The observance of standard clearance-limits requires frequent and careful attention. The most efficient means for detecting inconspicuous encroachment is secured on the Pennsylvania Railroad by the passage of a "clearance car" over the line. The apparatus for this purpose is attached to a cabin at one end of a flat car. It consists of sets of templates, to which are attached wire fingers or feelers. The main template has a width of 10 feet, extending from 2 feet to 12 feet above the top of the rail. Immediately in front of it is another template for measuring the clearance at bridges and in tunnels, at elevations of 17 to 20 feet above the rail, which may be illuminated by electric lights. The feelers are 2 feet long and 6 inches apart, hinged to the sides and top of the templates and held in position by friction. A board with a set of feelers one inch apart measures the projection of the cornices of adjacent roofs. Graduated scales indicate the distance of objects touched by the feelers. An attachment at the rear of the car indicates the degree of curvature on a scale within the cabin, and another shows the elevation of one rail above its opposite. With this apparatus, it is practicable to take measurements at a speed of 40 miles an hour, with an observer reading the scale and another person recording his readings.[1]

Monuments for Curves and Right-of-way

Points of curves should be indicated by monuments of stone or of concrete, placed between the ties on single-track and in the clear-way on double-track, and, at intervals, long tangents should be similarly preserved.

[1] The Railway and Engineering Review,

Changes of grade should be indicated by bench-marks. The same care should be taken of the boundaries of the right-of-way and of real estate. It is important that such boundaries should be clearly defined by substantial walls where such property is valuable, and elsewhere by fences of strong galvanized-wire netting and hardwood posts creosoted below the surface. These facts, together with the location of sidings, stations, road-crossings and water-tanks, should be shown on maps, on a sufficiently large scale, with symbols showing whether the right-of-way is held in fee-simple or by easement. On an accompanying profile of the line should also be indicated the natural contour, the location, size and character of all openings and of stretches of rail of different size and pattern. The same information should also be compiled in note-books of pocket-size for use out on the line. By such means, much time and expense will be saved in maintenance and in connection with proposed changes and improvements.

Signals and Interlocking Plants

The construction and maintenance of fixed train-signals is a function of the Roadway Department. With their more general use and the introduction of electric service, including light and power equipment, the signal engineer has become an important member of the Roadway staff. As the character and interpretation of signals for controlling the movement of trains pertains directly to the Transportation Department, attention here will be given only to the construction and maintenance of signal-apparatus. The earliest fixed signals on railroads in the United States were station sign-boards, mile-posts and crossing-warnings. To these were added whistle-posts for crossings and sign-boards for approaches to stations. It was not until the control of train-movements other than by time-table, passed, with the advent of the electric telegraph, from the train-conductor to the train-dispatcher, that fixed signals were established at the telegraph-stations to stop trains for orders. When the frequency of trains compelled the construction of a second track, fixed signals between such stations became track-accessories in connection with the block-system, which was introduced from England by the Pennsylvania Railroad management in 1845, and by 1864 it was extensively used on its lines.[1]

Fixed signals for controlling the movement of trains were developed from the principle of the indications given by the movable arms of the semaphore-telegraph which was introduced in England by the Admiralty between London and Portsmouth during the Napoleonic Wars. That principle has persisted in railway-signaling apparatus. It was first applied to indicate the movement of switches, and then the semaphore-arm was so connected with the switch-lever as to move with it. The colloca-

[1] The block system now covers the four-track lines from New York to Pittsburgh and from Philadelphia to Washington, and in three years to September, 1914, $6,000,000 had been expended in its extension.

tion of several switches led to their being controlled by a single switchman, stationed in an adjacent cabin and actuating them by connections composed of wires, rods, pulleys and levers. From such appliances was evolved the "manual control" system of interlocking switch-points with semaphore-signals known as the "Saxby" system, which came into general use in Great Britain after the year 1856. This system was further developed in the "block" system, with provision for signals to trains entering or leaving a block, which were operated from cabins adjacent to the signal-posts. Even at an earlier date, in 1844, the electric telegraph was employed in connection with the block-system on the Yarmouth & Norwich Railway. By 1873, there were 13,000 interlocking levers installed on the London & Northwestern Railway. A Saxby & Farmer machine was placed in service on the New York Central line, in 1874, at Spuyten Duyvil; but the first extensive installation in the United States was upon the New York Elevated Railway in 1877.

The interlocking of switches and crossings with signal-indications is an essential feature of the block-system. The purpose is to provide for the safe passage of trains over routes that may conflict with other routes; such as tracks crossing at grade, or the junction of two or more tracks, or at a draw-bridge. An interlocking-plant consists of an interlocking-machine, centrally located at a height affording a clear view of the line; signals to control trains passing over the several routes; and connections from the machine for operating and locking the signals and switches. The operating levers are so interlocked that it is mechanically impossible to give conflicting signals, or to give any signals until the switches have been properly set and locked.

Interlocking-machines operated solely through mechanical connections are more generally in use because of the comparatively low cost for their erection and maintenance. The lines of wire used in the older plants for connecting the levers with signals and switches, have been superseded by one-inch pipe traveling on anti-friction carriers. Expansion and contraction are provided for by a "compensator" in every seven hundred feet of line. Turns are made either by bell-cranks or by deflecting-stands supported upon concrete or cast-iron foundations, as are also the signal-masts of pipe set in sockets.

Electricity is used in mechanical interlocking for the operation of distant-signals, which are usually located on high-speed tracks at least half a mile from the home-signals whose indications they repeat; also for the announcement of approaching trains; for repeating the indications of signals invisible from the cabin; for locking certain routes when occupied by a train, and for other purposes. An electro-mechanical system has been devised in which, while the switches are manually actuated by mechanical means, they are locked and released electrically, and all signals are electrically operated.

The operation of signals and switches through mechanical means, is usually limited to distances of 800 feet for a switch and 2000 feet for a signal. Difficulties in operating mechanical connections beyond those limits, and in keeping lengthened lines in adjustment, have led to the intervention of inorganic forces in power-interlocking. The mechanical system is sufficient for operating a set of twelve to sixteen levers by a single attendant. Even with the aid of electric appliances, it works too slowly for a busy terminal. Under such conditions, power-interlocking becomes indispensable.

Power-interlocking is accomplished either by hydraulic, hydro-pneumatic, pneumatic, electro-pneumatic, electro-gas or all-electric power. Hydraulic action was combined with compressed air in the United States in 1884, but was superseded about 1891 by the electro-pneumatic system, in which compressed air, as the motive power, is controlled by electrically operated valves. About 1900, an electric motor system, or all-electric, system came into use.

Automatic Signals and Track-circuit

The first of the electric power-systems was developed in the United States in connection with the first automatic signal-system, known as "Hall's disk system," which was invented in 1871, and was introduced on the Eastern Railroad in Massachusetts, in 1872. In this system, the wheels of an approaching locomotive pressed upon a treadle beside the rail, which released a disk in the facing signal-instrument. For this purpose, the electric track-circuit was first employed; that is, an electric current that includes the rails as part of its path for changing the position of signals.

The continuous or "closed" track-circuit was invented by an American, William Robinson, in 1872. Mr. Westinghouse subsequently utilized compressed air to actuate a semaphore-arm in connection with the track-circuit in the "electro-pneumatic" system. An automatic signal-apparatus was patented in England by W. R. Sykes in 1872, but was not applied practically until the opening of the Liverpool Overhead Railway in 1893. An "all-air" or low-pressure pneumatic system was introduced from the United States on the London & Southwestern Railway in 1901. Automatic signals controlled entirely by track-circuits were installed on the Lancashire & Yorkshire Railway in August, 1906. Up to February, 1907, there was no method for actuating track-circuits by alternating currents. On electrically-operated railways, which used the running-rails for the return traction-current, automatic working was accomplished by "depression-bars" beside the rails, operating through solenoids upon the signals. The first automatic signaling on the London District Railway was opened in June, 1903. Automatic signaling on the Hall "normal danger" electro-gas system was installed on the Northeastern Railway, in August, 1904, on a branch-line of 10½ miles.[1]

The characteristic features of the automatic block-system are continuous track-circuits throughout the whole length of the track and the operation of each signal automatically by electric mechanism. The rails at both ends of the block are electrically insulated. To one end of the insulated section is attached a battery of one or two volts. The opposite end is connected to a resistance-coil which opens and closes the controlling circuit of a power-operated signal. The relay thus energized closes the local circuit of the signal, which is thereby raised to the inclined or "clear" position. As soon as the first wheels of a train enter the block, the electric current is short-circuited through the wheels and axles from one rail to the other, instead of continuing to the relay which, being thus deprived of electrical energy, allows its contact to open. This action de-energizes the magnet which holds the signal-arm in the "clear" position, and the arm then falls by gravity to the horizontal position and so remains until the last pair of wheels in the train has left the block, when the signal again assumes the inclined or clear position. By the use of special circuit-controllers, or "switch-boxes," the opening of the points of any switch in a block instantly causes the signal at the entrance of the block to assume the horizontal position; also, the breaking of a rail under a train, by similarly interrupting the continuity of the track-circuit, prevents the signal from returning to the inclined position, even after the train has left the block. The maximum length of a track-circuit is usually about a mile, except under favorable local conditions; but two or more sections can be relayed in succession to any required distance, as may be demanded by traffic-conditions.

Electric Interlocking

By the electric-pneumatic apparatus, which was successfully introduced in 1891, valves, electrically controlled by levers in the machine, admit or release compressed air in the working-cylinders and the resulting movements of switches and signals are accompanied by switch and signal indications, to insure that each switch or signal shall follow the movement of its appropriate lever or, failing to do so from any cause, that no unsafe condition shall ensue. The electric mechanism pulls "clear" as soon as there are no wheels in the insulated block-section, and releases the danger-signal as soon as wheels enter the section, or when, from any cause, the track-current is interrupted. Air, at a pressure of 80 to 100 pounds per square inch, operates single-acting cylinders by means of the electrically-controlled valves.

The switch-and-lock movement consists of a double-acting cylinder, an electric valve and the movement itself, secured to a base-plate and

[1] See C. H. Ellison, Railway Gazette, London, March 9, 1917.

bolted to the ties. In one complete movement of the piston, the switch is first unlocked, then moved and finally relocked in the opposite position. The movement is connected to a "detector" bar 50 feet long, or to a series of such bars, lying alongside the rail in brackets. Every time a switch is shifted, the detector-bar must first be raised and lowered. When a train stands upon or moves over the rails, the bar attached to them is held from rising by the tread of the wheels and thus prevents the switch from being moved. This safety device is also used in mechanical plants. Most of the great terminals in the United States are equipped with the electro-pneumatic interlocking-apparatus.

In the electro-gas system, liquid carbonic-acid gas, instead of compressed air, is used to move the semaphore-arm from the horizontal to either the inclined or the vertical position, and held in position by an electrically-controlled latch.

The electric-motor system, or "all-electric" system, was first used in the United States in 1898, and is installed upon the electrically operated lines of the Pennsylvania Railroad and the Long Island Railroad in and around New York City. In March, 1910, there were 34,696 of these appliances in service. All the operations are performed electrically, though on the same principle as in the electro-pneumatic system, using 110-volt direct-current motors for operating switches and high signals, and solenoid-magnets for low or "dwarf" signals. Current from storage-batteries in the cabins drives a train of gears, engaging in the ends of levers, or "slot-arms," that are connected to the semaphores by vertical rods extending upward through the hollow mast, and the semaphore-arm correspondingly moves by means of levers and electro-magnets. But one motor and set of gearing are required for any number of arms on a single post. The electric mechanism pulls "clear" as soon as there are no wheels in the insulated block-section, and releases the danger-signal as soon as wheels enter it, or when, from any cause, the track-current is interrupted. One rail is used solely for operating the signals. The other rail is used in common with other circuits; the relays for the signal-current being operated at a higher voltage than the return track-current. An alternating-current may be substituted for signal-operation in conjunction with a relay that is irresponsive to direct-current. A signal-system on this principle was installed on the Boston Elevated Railway in 1900.

In several plants, working-models in the cabin automatically indicate the presence of trains in each of the sections into which the tracks are divided. By this means, the lever-man can operate the plant without actually seeing either the tracks or the trains.

In another electric system, metallic conductors, or "inductive bonds," placed at each end of a block or sub-section, carry the return traction-current around the insulated joints, but prevent the passage of the alternating-current from operating the signal-circuit. By this means, both rails can be used for that circuit and for the return traction-circuit, whether that be on the direct or the alternating system. The alternating-current is also used for the operation of signal-motors and electric locks, and for other appliances of automatic block-systems, as also for lighting the signals.[1]

Interlocking machinery has made it possible to operate extensive terminal-yards with facility, economy and safety. The interlocking-plant at South Station, Boston, includes nine signal-bridges and a tower containing an electro-pneumatic plant of 165 levers. In this terminal, there are about 850 train-movements a day, and almost 100 per hour during the rush-hours. At the Hoboken terminal of the Delaware, Lackawanna & Western Railroad the traffic is handled from three interlocking-plants, controlling 627 signal-units. From April, 1913 to April, 1914, there were nearly 29,000,000 switch-and-signal movements, of which but 36 were imperfect. The switches and signals at the Grand Central Station are operated by five all-electric plants, with a minimum of 80 levers and a maximum of 400 levers in the several plants. There are also twelve sub-stations for localizing and housing relays and track-apparatus.[2]

Position-light Signals

Colored light signals, composed of an ordinary incandescent lamp in a box behind a lens, have long been in use on trolley-roads for both day and night indications, and on steam-roads in tunnels. But a remarkable innovation in track-signaling has been introduced in the "position-light" signal-system, in which the form aspects of the semaphore-indications are given either in the day or the night by a series of uncolored lights.

In 1914, Dr. Churchill, of the Corning Glass Company, while working on electric headlights, found it possible to secure a long range from a small source of light, if it were placed at the focal point of a suitable lens; and, in collaboration with Mr. A. H. Rudd, signal engineer of the Pennsylvania Railroad Company, arranged a combination of such lights in rows, having the effect of a semaphore-arm and doing away with the color scheme. This arrangement was carried into practical effect by the installation of a "position-light" signal-system on a section of the Philadelphia Division of the Pennsylvania Railroad, which was then being electrified. The system is now in use from Overbrook to Paoli on 15½ miles of four-track line, and at other localities on that railroad, where it has met with such favor that its use is being constantly extended.

Each unit consists of a container, or box, painted dead-black inside, holding a 12-volt, 6-watt, horizontal helical-filament tungsten-lamp, in the exact focal point of a toric[3] inverted lens of 2¼ inches' focus and 5⅜

[1] For more detailed information, see "Railway Signalling in America," J. S. Hobson. Cassier's Magazine, March, 1910. Fully illustrated.

[2] "Passenger Terminals," J. R. Droege, pp. 49, 55, 114.

[3] Toric. — A surface generated by the revolution of a conic (especially a circle) about an axis lying in its plane. — Century Dictionary.

inches in diameter, in front of which is a special convex cover-glass of the same diameter. Over the lens, a 4-inch spherical mirror is placed at such an angle that no light can be reflected outward, and that no unlighted unit can appear to be lighted. The cover-glass is of a light-yellow tint, which is much easier to the eyes than white light. For dwarf-signals, the cover-glass is "frosted." The entire range of aspects on the two-arm system, as required in standard practice, may be displayed by sixteen lamps in two groups respectively of ten and six lamps each. The interlocking signals are given by a group of three units.[1] The signals can be operated with half the current consumption required for the usual colored-light signals, and consequently at half the cost of operation. By doing away with all moving parts except relays,[2] the chances of false "clear" indications are reduced to a minimum. For indications in a fog or snowstorm, these signals are thought to be better than any others.[3]

Signal Statistics

On January 1, 1901, the manual-controlled system was in use on 24,013 miles of line in the United States, and automatic-systems on 2295 miles, being a total mileage of 26,308 miles under block-systems. On January 1, 1908, there were 58,768 miles of line under block-systems, and 86,731 miles on January 1, 1914. At the earlier date, 39 per cent. of the passenger-line mileage was so operated and 46 per cent. on January 1, 1914. In 81,736 miles of this latter mileage under block-systems, there were 60,167 miles operated under the manual system and 26,569 miles under automatic systems, the electro-motor system being in general use. On January 1, 1908, out of 44,165 miles of line under the manual system, the telephone was in use on 3287 miles in place of the telegraph. On January 1, 1914, out of 60,125 miles under that system, the telephone was in use on 26,241 miles. At that date, there were 848 interlocking-machines in use, with 17,951 working levers. Of these machines, 632 were mechanical, 122 electric, 48 electro-pneumatic and 46 were electro-mechanical. There were 5884 switches interlocked and 4069 derailers.[4]

In 1890, 98 per cent. of the line mileage in Great Britain and Ireland was equipped with block-signals. In 1915, with about 24,000 miles of line, there were about 310,000 levers in use in the manually-controlled system; including working-points, facing-points, locks and signals.[5]

[1] See Appendix VII, Note VII.

[2] Relay.—An electro-magnet designed to repeat the effects of an electric current in a second circuit.—Signal Dictionary. Railway Age Gazette, Publishers.

[3] See "First Position Light Signal Installation," C. E. Goings.—Signal Engineer, March, 1915.

[4] See Appendix V, Table XVII to XX.

[5] For progressive development of block-signals and interlocking, see Appendix V, Table XX.

Snow-sheds

The exigencies of railway operation at high altitudes in an inclement winter climate have led to the development of snow-shed construction on the lines crossing the Continental Divide. Experience with this form of protection on the lines of the Southern Pacific Company is set forth in Appendix V, Table XXI. On the Canadian Pacific Railway, seven miles of snow-sheds, containing 26,000,000 feet of lumber were built at a cost of $3,000,000. On the Great Northern Railway for ten miles down the western slope at the end of the Cascade Tunnel, 76 per cent. of the distance has been protected at a cost of nearly $1,500,000. These sheds have concrete retaining walls and a timber roof designed for a load of 1500 pounds per square foot. At two points, concrete galleries which are practically double-track tunnels have been built in open side-hill cuts, for protecting approaches to rock tunnels.

Water-stations and Tanks. Track Water Trough

Among the structures connected with the Motive Power Department, water-stations come more directly under the control of the Roadway Department. There has been great improvement in these stations since the days when the water-tank was a mere tub held together by light iron hoops and unprotected from the summer sun and winter's frosts, save in very cold climates. Thus exposed to the vicissitudes of the seasons, the staves shrunk apart above the average water-level; the hoops expanded and contracted until the lugs by which they were bolted together gave way; the outlet-valve leaked and water constantly dripped along the track from the canvas hose. A hand-pump supplied the leaking tank from a well that frequently went dry, and then information went along the line by word of mouth that no water was to be had at that station. This was not an unusual condition as to the water-supply in the early days of railway operation in the United States. With the general improvement which has taken place in railroad service, this situation has been greatly changed. Steam-pumps have supplanted manual labor and horse-power. The sources of water-supply are of a more reliable character, frequently remote from the station and connected with the tank by a main and standpipe.

Tanks up to 50,000 gallons' capacity and 30 feet in diameter are still made of staves. The staves are of a uniform width from 6 to 8 inches, 20 feet long and 3 inches thick, with bottom planks 12 inches wide. The staves and bottom are joined by one-inch dowel-pins. The hoops should be of extra tensile strength, as the failure of wooden tanks is principally due to defective hoops. In some cases, the tank rests upon a steel substructure, but it is usually supported upon a frame of closely spaced joists, borne by twelve posts of 12 by 12-inch timber, preferably of material that has been preservatively treated.

Tanks of 50,000 to 100,000 gallons' capacity are built entirely of steel. At first they were flat-bottomed, but since 1894 they have been built either with conical or hemispherical bottoms, supported by steel columns, attached directly to the sides of the tank, and with a mud-drum in which matter suspended in the water is precipitated. They are provided with inside and outside ladders and a water-gauge, and the other accessories are well thought out and substantially made. Tanks should be covered with a conical roof, having a pitch of $1\frac{1}{2}$ inches to the foot and 14-inch eaves, and covered with composite roofing-material.

In designing steel tanks, it is usual to assume the weight of water at $8\frac{1}{3}$ pounds per gallon and $7\frac{1}{2}$ gallons per cubic foot or, more conveniently, at $62\frac{1}{2}$ pounds per cubic foot; allowing foundation-pressure on dry sand or clay of 3 tons per square foot, and $\frac{1}{4}$-inch minimum thickness of cylindrical sheets.

The progressive demand upon a water-station which accompanies increased train-service is illustrated by the experience of the Illinois Central Railroad Company at Centralia. At this station, the demand increased from 72,000,000 gallons in 1895 to 141,000,000 gallons in 1905, and to 280,000,000 gallons in 1914. Efforts to diminish the waste of water resulted, in 1915, in a reduction of the demand by 42,000,000 gallons. In 1855, the supply was furnished from a creek by horse-power, for which a steam-pump was substituted in 1858. In 1859, the creek was dammed to form a reservoir. In 1865, two 40,000-gallon tanks were erected. In 1909 in combination with the city authorities, a reservoir of 1,000,000,000 gallons was formed by building a 650-foot dam across a valley, eight miles from the pumping-station, to which the supply was delivered through a 20-inch main of wooden staves.[1]

To avoid stopping high-speed trains for water, Mr. Ramsbottom devised a plan for "picking up" water from long and shallow troughs between the rails, which was introduced upon the London & Northwestern Railway in 1857, and on the New York Central & Hudson River Railroad in 1870. It is now in use on all the trunk lines for express-trains operated at very high speed. The troughs must be placed upon a level piece of track, but not necessarily on a tangent. They are from 1000 to 2000 feet in length, and even 2500 feet for watering two locomotives in a double-header. They are made of sheet-steel, $\frac{3}{16}$ inch thick, 6 to 7 inches deep and 19 to 24 inches wide, with the top of the trough level with the top of the rail. The trough is anchored to the ties about the middle, to allow for expansion. The bottom slopes upward toward the ends, which are protected externally by inclined planes.

Water is supplied through a main with several branches. On double-track, the troughs are connected by piping, and, with three $3\frac{1}{2}$-inch pipes,

[1] "The History of a Water Station," C. R. Knowles. Railway Age Gazette, June 10, 1916.

a double-tank may be filled in six minutes. The connection to the troughs is made either by rubber-hose or by an expansion-joint to provide for changes of temperature. In severe weather, it is necessary to pipe steam into the troughs to prevent freezing. Drainage should be well cared for.

The water is taken into the tender by a hinged scoop which is dropped into the trough by a lever. Signals near the trough indicate the points at which the scoop is to be lowered or raised. The scoop is 12 inches wide with a goose-neck spout, oblong in section, to fill the tender. A stop in the scoop prevents it from touching the bottom of the trough, and water can be taken at a speed of seventy miles an hour. On the Baltimore & Ohio Railroad, between Baltimore and Philadelphia, 92 miles, track-tanks are placed 30 miles from each end.[1] The Pennsylvania Railroad has every locomotive equipped with a scoop, and slow as well as fast freight-trains and passenger-trains all take water without stopping.

Locomotive Houses

The building, or "roundhouse," for housing locomotives, should have stalls for at least one-fourth of the number of locomotives normally passing into and out of the terminal yard. There should be a smoke-jack over each stall, with liberal provision for the exit of smoke and a monitor-roof for light and ventilation; which diminishes also the corrosive effects of coal smoke upon an iron roof. Perhaps a floor of concrete is preferable to one of brick. A portable gantry crane is useful in a house not fitted with hoists.

For housing less than ten locomotives, the simplest arrangement is a set of ladder-tracks entering on a skew into a rectangular shed, and requiring neither a turntable nor a transfer-table; but a greater number must be housed around a turntable, which should not be less than 75 feet in diameter.[2] The angle of the adjacent tracks should be an even factor of 180°, so that they will be in line across the table. The maximum number of stalls in a complete roundhouse depends upon the arrangement of the tracks; whether they are laid independently to the edge of the table or intersect between the table and the house. The maximum number of stalls in the former case would be about thirty, and sixty in the latter. For a greater number, the plan of the house would be two semicircles spaced apart, with a table in the center of each. The distance between the inner and the outer walls of the roundhouse should not be less than 100 feet, to provide space for working around modern locomotives, which vary in length of engine and tender from 78 feet up to 88 feet for an articulated locomotive, with an engine wheel-base of 58 feet. The house should be

[1] See "Notes on Track," W. M. Camp, 1903.

[2] At Towanda, Pa., on the Lehigh Valley Railroad, seven locomotives are housed in a shed 63 by 183 feet, with tracks 13 feet between centers and 18 feet on a skew of 46°. "Freight Terminals," J. S. Droege, p. 388.

lighted through the closed doors as well as through the outer wall. It should be heated by hot blast and ventilated through a monitor roof. The smoke-jacks should be at least 30 inches in diameter, with suction-ventilators and hoods. The minimum clear opening of the doors should be 12 feet in width and 17 feet in height. The locomotives should head toward the outer wall to give space and light at the front end, where they are most needed. Each stall should be provided with hot and cold water, compressed air and electric current. The pits should be at least 60 feet in length, with a convex bottom sloping from 2½ feet to 3 feet in depth and drained into the turntable-pit, the walls of which should be of concrete with a wooden coping, 6 inches thick. The circular track and the pivot should rest on concrete foundations. Between the yard-entrance and the turntable there should be access to water-columns, coal-chutes, sand-bins, ash-pits and inspection-pits, with separate tracks for incoming and outgoing locomotives and standing-tracks for as many of them as there are stalls in the roundhouse.

The increasing length of locomotives has, in several instances, necessitated the substitution of longer tables and even the reconstruction of roundhouses.[1] On this account, it would seem that a house of rectangular plan, in connection with a "Y" track and a transfer-table, would be preferable to a roundhouse and turntable. For an equal length, the transfer-table may be of simpler and lighter construction, as the weight may be borne on two or more tracks instead of being concentrated on the center-bearing. Rectangular bays may be of any desired width with less waste-space, and would afford readier access to all parts of the locomotives standing in them. The rectangular roof would be of simpler design, and the building could be extended as additional standing-room was required. If the shop for running-repairs were attached to the rear of such a building, several bays could have independent access to it.

Coaling-stations

Important coaling-stations are now substantial structures, designed to meet local conditions, with conveyors to elevate coal into pockets, whence it is discharged through chutes, and with accessory sand-bins. Such a station has recently been built of reinforced concrete at Proctor, Minn., on the Duluth, Missabe & Northern Railway. It has storage capacity for 1000 tons, serving a track on each side and receiving coal from a track beneath the storage-room. Sand is contained in a separate concrete

[1] On the Atchison, Topeka & Santa Fé Railway it was required to provide for Mallet locomotives measuring 89 feet 2 inches between centers of end-wheels. The 85-foot table was replaced by one 97½ feet in length, counterweighted at the motor-end, at which all loads entered, in place of a tilting arrangement. This table has handled 51 locomotives in three hours. (Railway Age Gazette, August 18, 1916.) Turntables 105 feet in diameter are in use on the Buffalo, Rochester, and Pittsburgh Railway.

structure, outside of a coaling-track. Wet sand is elevated by the coal-conveyor to the top of the tower and descends by a chute into the drying-house. Thence it is returned by compressed air into a bin in the coaling-station.[1] On the Atchison, Topeka & Santa Fé Railway there are coaling-stations of reinforced concrete, designed as a cylindrical tower, with a shell 9 inches thick and capacity from 250 to 300 tons. The tower is 23 feet outside diameter and 89 feet in height from footing to roof. The coal-bin is in the upper 29 feet, with a concrete bottom and a chute 35 inches in diameter. There is also a sand-drying plant.[2] Water-stations are usually spaced from 15 to 20 miles apart, and coaling-stations from 60 to 70 miles.

Coal should not be shoveled from a car to a platform and thence into the tender, requiring the labor of from five to ten men. Even where the consumption is small, it would be more profitable to use a coaling-crane and buckets. With increasing consumption, a location should be selected where the coal can be unloaded from an elevated track to a platform at such a height that it can be dumped from barrows into the tender. Such barrows are usually 6 feet long, 30 inches wide and 30 inches deep, with a capacity of 38 cubic feet. Each barrow-load should be weighed. Better still, the coal may be discharged into pockets and delivered through chutes into the tender. The approach to the elevated track is ordinarily from 400 to 600 feet in length with a rise of 3.5 to 5 per cent. The pockets have a slope of not less than 45° for bituminous coal, or 35° for anthracite. Where a reserve of coal is stored on the ground, it may be reloaded with a steam-shovel.

Coal-handling and Coaling-plants

In the transshipment of coal, the loaded cars may ascend by inclined planes to the height required for delivery into "pockets." At points of delivery for water-transportation, either on the Great Lakes or on the Atlantic Coast, this operation calls for engineering works of great magnitude. On the Atlantic seaboard, there are four harbors of importance where coal is discharged directly into shipping, — New York, Philadelphia, Baltimore and Norfolk.

In 1913, there were in use thirteen coal-ports in New York harbor with 29 plants; in Philadelphia, three with 11 plants; in Baltimore, four with 8 plants; and in Norfolk, three with 8 plants; there were two additional plants under construction at Philadelphia, and two at Norfolk. In that year, about 1,050,000 cars were unloaded at these ports. As the average car-load is about 42 tons, the total tonnage was about 44,000,000 tons. From 1903 to 1911, both included, the ratio of maximum output per

[1] "A Large Reinforced Concrete Coaling Plant." Railway Age Gazette, September 29, 1916.

[2] "New Type of Coaling Station." Railway Age Gazette, August 25, 1916.

annum at these ports to the estimated capacity of the coaling-plants averaged in New York, 51 per cent.; in Philadelphia, 29 per cent.; in Baltimore, 31 per cent.; and in Norfolk, 30 per cent.

At their average estimated capacity, these ports could have discharged the actual output of 1911, in 222 days, at New York; in 185 days, at Philadelphia; in 195 days, at Baltimore; and in 141 days, at Norfolk.

From this statement, it appears that the then existing plants were capable of supplying a greater demand for coal than was required. The necessity, however, of being in a position to furnish large cargoes in a short time has led to the construction of piers of greater capacity than is usually required. The capacity of many of the piers is restricted by lack of yard-facilities. At several of them, the height is insufficient to admit of a free discharge of coal from the pockets to the vessels. In New York, there is an almost continuous run of cargoes of from 50 to 3500 tons for local consumption, which is not nearly as great in other harbors.

The total capacity of these several coaling plants in 1911, per day of ten hours, was 2700 cars of anthracite, and 1650 cars of bituminous — total 4350, in New York; 2640 cars in Philadelphia; 3180 bituminous in Norfolk; and in Baltimore, 260 cars of anthracite, and 830 cars of bituminous — total 1090; or 11,260 cars at the four ports.

The piers with the greatest capacity per day of ten hours were the Pennsylvania Railroad piers in New York, 300 cars, and in Philadelphia, 350 cars; the Baltimore & Ohio Railroad piers in Baltimore, 300 cars; the Norfolk & Western Railroad piers at Lambert's Point, Norfolk, 400 cars; also in Norfolk the Chesapeake & Ohio Railway piers at Newport News, 380 cars, and the Virginian Railway piers at Sewell's Point, 300 cars.

The plants under construction for the Norfolk & Western Railway Company and for the Chesapeake & Ohio Railway Company are each to have a maximum capacity of 600 cars. The Pennsylvania Railroad Company constructed, in 1916, at Canton Wharves, Baltimore, a pier 66 feet wide and 942 feet long, in connection with a yard having trackage for 1000 cars and a capacity for loading 20,000 tons daily. At South Amboy, one pier of the Pennsylvania Railroad coaling-plant has a maximum capacity of 140 cars of anthracite or of 300 cars of bituminous coal. In New York harbor, sea-going vessels are usually coaled from lighters. In Philadelphia harbor, the greater portion is in barges for domestic use; though tramps are loaded with from 5000 to 7000 tons. In Baltimore and in Norfolk harbors, tramps and colliers are loaded up to 12,500 tons; a large part of these cargoes being for New England ports or for foreign countries.

Coaling-plants may be classified as gravity-plants, mechanical plants or "combination" plants. In the gravity-plants, coal-trestles are equipped with pockets for receiving the coal and with chutes for discharging it into vessels. Some of them are on grades that permit cars to drift over the deck-tracks and then return empty to the yard by gravity. In others, power is required for these purposes. Mechanical plants are equipped with car-dumping machinery, elevators and conveyors for delivering the coal without the use of tracks or trestles. The car-dumpers pick up the cars and dump the coal on an apron whence it flows into adjustable chutes which are kept full to reduce the fall and breakage. In some of the plants, the cars are dumped into conveyor-buckets, which lower the coal to the bottom of the hatch, in order to lessen the breakage. Where the space is restricted, the cars are lifted vertically, and then dumped sidewise into the chutes. Cars may also be hauled up a cable-incline to be turned sidewise into the dump or into a self-propelling transfer-car having a sloping bottom, which enters a tower that is moved on tracks along the pier, and is then hoisted to the proper height to be emptied into the chute. Where the tracks are at right-angles to the piers, the coal is dumped into a hopper and elevated by endless-chain conveyors to a height sufficient to flow into the pockets. Car-dumping machinery is combined with gravity-plants in a variety of ways. There are 50 gravity-plants, 7 mechanical plants and 3 combination plants in operation on the Atlantic seaboard.

The longest coal-pier is at South Amboy, 1800 feet from bulkhead to end of slip. Other piers have slips from 735 to 1200 feet in length. Two piers under construction at Lambert's Point and at Newport News, in Norfolk harbor, are to have a width of 91½ feet, with a maximum height of 47 feet from the discharging end of the chutes to the water-surface, and a minimum height of five feet. To coal freely into coastwise shipping, the piers ought not to be less than 65 feet above mean tide, when the pier is not provided with storage-bins. For bins storing a car-load of coal each, the height should be 70 feet above mean tide.

The tracks leading to the piers and yards should be arranged to require as little shifting of cars as practicable. To sort cars with different kinds of coal, a number of short tracks is desirable; preferably a gridiron with a ladder at each end. The approach-tracks to locomotive-inclines should have sufficient length to allow a good run for ascending the incline. The approach-tracks to a cable-incline should be down-grade, so that loaded cars may drift down to it, as they are wanted. The grades on locomotive-inclines vary from one to five per cent., according to the length of the pier, the power of the locomotives and the discharging-capacity of the pier. As a general rule, the grades should not exceed three per cent. The grades on cable-inclines may vary from 16 to 18 per cent., and on mechanical dumps from 10 to 12 per cent. The grades on pier-decks should be just sufficient to allow cars to move slowly by gravity, say from 0.5 per cent. to 1.5 per cent. Grades for the return-tracks should not exceed 2 per cent. for hand-brake control. All changes of grade should be eased by vertical curves for a distance of 35 to 50 feet.

The delivery-track is sometimes connected with the return-track by a switch-back, constructed with adjustable blocking, so that the cars will move by gravity at suitable speeds in either warm or cold weather. Where there is not room for a switch-back, counter-balanced transfer-tables, pivoted at one end, are used. As a car is run on to the table, the table swings in line with the return-track to which the car runs by gravity. The table is then returned to its normal position by a counter-weight.

The equipment connected with a gravity-pier consists of bins for storing coal, chutes and pockets for delivering coal directly from the cars to the chutes, track-scales and thawing-plants. The bins are built beneath the approach-trestle and are so constructed that the coal is dropped from the car-bottoms through openings in the deck, and may be discharged through hopper-bottoms into other cars beneath or by chutes into barges. Pockets are placed under the delivery-tracks on the pier with their bottom-outlet at the side of the pier. For the pocket to receive the full discharge of coal from either a hopper-car or a gondola-car, its top should be at least 12 feet long and 9 feet wide, with the sides and bottom tapering toward the opening at the side of the pier.

There are several types of chutes, either simply hinged or adjustable at either end, or with a telescopic leg at the lower end; but the simple hinged chute is preferable for its simplicity, speed of delivery and low cost of installation and maintenance. This, however, depends also upon commercial conditions; as the cost of trimming in the ship's hold and the damage to the coal from excessive breakage, may offset these advantages to a large extent. It is, after all, a question of the quick release of vessels of large daily tonnage and a consequent reduction of expense in operation.

Track-scales are connected with coaling-plants where required by local conditions. They should be so located as to require the least shifting of cars and be convenient for observation, with length suitable for the standard length of cars, their moving speed while being weighed, and as to whether they are weighed singly or while coupled. They are from 34 to 64 feet in length, if fitted with automatic weighing devices, or from 32 to 60 feet, if without them. On the new piers in Norfolk harbor, the automatic scales are 68 feet long, with weighing capacity from 160,000 to 300,000 pounds.

There are several plans for thawing frozen coal, either by inserting steam-jets from a locomotive or from a stationary boiler, or under cover by hot air; but where thawing is only occasionally required, it is customary to break the frozen coal by hand.[1]

Many of the appliances here described for the transshipment of coal from rail to water, originated at ports on the Great Lakes. In their development, remarkable ingenuity has been displayed in the substitution of machinery for manual labor. Their general use brought about the construction of coal-carrying ships of large tonnage, with hatches and

[1] "Coal Piers on the Atlantic Seaboard," J. E. Greiner. Trans. Am. Soc. C. E., December, 1914.

holds specially planned for the receipt and discharge of cargoes by these appliances. The effect of these various improvements has been shown by the reduction of Lake rates from 90 cents per ton of 2000 pounds, in 1887, to 30 cents in 1912.

The car-dumper, introduced in 1892, has been so developed that it will now seize a 50-ton loaded gondola-car, weighing (gross) 140,000 pounds, inclose it in a cage, raise it on high, swing it out over the dock and capsize its contents into a vessel's hatches at the rate of forty car-loads an hour. The breakage of coal in this process is lessened by its delivery through a telescopic chute extending to the bottom of the hold, which is gradually withdrawn as the cargo accumulates.

In the seven months of open navigation, it was necessary to accumulate at Lake Superior ports, the fuel required in the Northwest for the ensuing winter season. Here, again, American engineering genius devised the means for accomplishing this duty, and, for this purpose, large expenditures have been made by the railroad companies, with more regard to social efficiency than to direct profit. The means devised with this object in view, are the grab-bucket to unload coal from vessels, and the bridge-conveyor for distributing it in a spacious storage-area.

The conveyors are built to cover an over-all length of 200 feet, and are equipped with a seven-ton self-righting tub for distributing the coal, and a four-ton shovel-bucket for reloading it into cars; each handled by one man and all operated electrically. Intermediately, each load is automatically registered. Some of these plants can unload a cargo of 5000 tons in ten hours, and distribute it over an area 275 feet wide and 900 feet long, with a storage capacity of 150,000 tons. In 1906, a covered anthracite-plant was installed, in which 200,000 tons are piled 60 feet in height. The shipment of coal from lake ports into the Northwest is largely in returning grain-cars. A special loading-appliance has been devised for loading such cars directly from the storage piles.[1]

Grain Handling

The Atchison, Topeka & Santa Fé Railway Company has an elevator at Chicago with facilities for receiving and delivering grain at the rate of 15,000 bushels an hour. The plant consists of an elevator-house, a storage-annex, a drying and bleaching equipment and a marine tower for delivery to shipping; the whole being operated by 1500 horse-power. The elevator house is 225 feet by 83 feet and is 170 feet to the top of the cupola. It has a timber-frame closed in by brick-walls 80 feet to the top of bins of 400,000 bushels' capacity. The cupola above is covered with corrugated steel. The bins are raised 40 feet above the ground floor, on which is placed the machinery for handling grain from five receiving-tracks. Eighty cars are

[1] See "The Handling of Coal at the Head of the Great Lakes," G. H. Hutchinson. — Journal Am. Soc. Mechanical Engineers, August, 1914.

set on these tracks at one switching operation, and these cars are placed in position by a car-puller, twenty cars at a time. The grain is discharged into hoppers beneath the tracks; each containing a full car-load. Each group of four hoppers discharges into a conveyor for delivery to the receiving-plant beneath the bins; here it is elevated into the cupola, where it is weighed and dropped into the bins; or spouted into cars for transshipment; or delivered to the marine tower; or conveyed to the annex. The annex has a capacity of 1,000,000 bushels, stored in 35 concrete-bins, each 23 feet in diameter, and in the interspaces.

At Victoria Harbor, Georgian Bay, grain is transferred from lake vessels to the Canadian Pacific Railway by means of two movable towers of steel, traversing the dock-front on a double-track. Each tower, 170 feet high, is carried on ten freight-car trucks and is moved by a cable-pull. There is storage-capacity for 2,000,000 bushels in 32 concrete-bins, 35 feet in diameter, with storage also in the interspaces. This plant is operated by electricity and has a working-capacity of 20,000 bushels an hour.[1]

Ore Handling

The shipment of ore from ports on Lake Superior to Lake Erie ports has reached 50,000,000 tons in seven months of open navigation. The appliances originally devised for handling coal have been modified for handling this vast tonnage. At one of the ports on Lake Erie, there is a storage-yard covering 50 acres, with a concrete dock-wall 800 feet long, furnishing space for 1,000,000 tons of ore. Four unloaders, each carrying a 17-ton bucket, span four tracks, and a cantilever-extension enables them to discharge ore 110 feet inward from the dock. The outreach of the bucket-arm is sufficient for the bucket to be lowered into the hold of a vessel 65 feet from the face of the dock. The bucket-shells, when open, have an expansion of 21 feet 3 inches and a telescopic motion of three feet. It takes 50 seconds for a complete movement, which is equivalent to a capacity of 1000 tons per hour for each of the four unloaders. Ten-thousand-ton cargoes have been unloaded in less than three hours. The ore is distributed over the storage-space by a traveling-gantry with a main span of 266 feet and a cantilever at each end of 170 feet. The ore is grabbed from the vessel's hold in the unloading-bucket, elevated by the rocking-arm and discharged into a 60-ton hopper, from which it passes into a 50-ton scale-car, and then into cars or into a temporary storage-pile, from which the bridge-conveyor transfers it to the main storage-space.[2]

[1] "Freight Terminals," Droege, pp. 269, 272.

[2] An interesting use is made of electro-magnetism in connection with handling pig-iron. At the dock of the Buffalo, Rochester & Pittsburgh Railway in Buffalo, a locomotive-crane mounted on standard freight-trucks is equipped with an electro-magnet with a carrying load of 3250 pounds. The boom is over 40 feet in length, with capacity for a load of 31,500 pounds and 24 per cent. overload in a radius of 13 feet, or a load of 6500 pounds with 23 per cent. overload in a radius of 44 feet.

Dock and Harbor Facilities. Miscellaneous Freight

The proper alignment of yard-tracks with reference to the bulkhead-line of a dock, depends upon the surrounding conditions, as well as upon the character of the commodities for transshipment. Where the harbor is spacious and the access to it is level and free from encumbrances, the piers may project at right-angles to the bulkhead line, the switching-tracks approaching perpendicularly; though with long trains and several piers, such a track-plan may interfere with the general arrangement of the terminal yard, besides requiring sharp curvature in the leads to the outer switching-tracks. Where the harbor is contracted, as in the channel of a river, and it is practicable to locate the approach to the harbor on an alignment approximately parallel to the bulkhead-line, sharp curves in the switching-tracks are avoided by projecting the piers at an acute angle to the bulkhead-line, on what is known as the "saw-tooth" plan. On this plan, the tracks switch on to the piers from the same side of the approach-track, and all with the same degree of curvature. The approach-track may be continued indefinitely to serve any number of additional piers, and the return-track can be parallel to it with cross-overs. The side of the yard away from the piers is then favorably disposed for a connecting grid-iron, or for general switching purposes. Such an arrangement is suitable for shipping lumber in large quantities, as the lumber can be stacked more conveniently for loading through the bow-ports of a vessel. In a narrow river, the slips should open toward the entrance, which makes it easier for a vessel to enter or leave them without blocking the main channel.

The Dominion of Canada has undertaken the establishment of a harbor-terminal at Halifax in connection with its system of transcontinental railways. The estimated outlay of $30,000,000 includes the construction of an entirely new railway-entrance to the city and six miles of approach-tracks, with a passenger-station adjacent to a quay 2000 feet in length, and six piers, each 1250 feet in length in 45 feet of water, providing berths for twenty to thirty of the largest steamships afloat; also a protective break-water and all the equipment required for economical transshipment between railway and steamship.

Covered piers are required for the transshipment of miscellaneous and package freight. The deck of such a pier should be level with the car-floors for convenient trucking. Where there is a considerable rise of tide, this requires that slip-ways should be cut in the side of the pier to suit the side-ports of a steamship and to avoid hoisting through the hatchways. At low tide, the ascent of the slip-way is a serious draft upon the strength of a truck-hand. This difficulty is overcome by the introduction of the moving ramp or "escalator," now in common use for passenger-service between different levels. As modified for this purpose, it consists of an endless steel chain, revolving about sprocket-wheels that are driven by a motor. It can be started, stopped or reversed at any point during its travel. The truck-hand brings his loaded truck to the foot of the ramp, whence man and truck are transported from the ship's deck to the pier-deck, quickly and without physical effort. It is asserted that the "single-file" machine has a capacity of 600 trucks per hour, and that the "duplex" machine will double that duty, with the ascending and descending machines both in operation. On a pier now under construction in Norfolk harbor, there will be 35 of these machines in service.

The transshipment of miscellaneous freight at New Orleans has been recently facilitated by the construction of a terminal yard on the bank of the Mississippi River by the State of Louisiana at a cost of $3,500,000. The terminal covers 150 acres, of which 100 acres are occupied by 22 miles of tracks. Twenty-three acres are under roof, with storage-capacity for 2,000,000 bales of cotton, and other provision for storing sugar, rice, tobacco, coffee, corn and wheat. It is equipped with 4½ miles of overhead and floor-level runways and 50 miles of runways for traveling-cranes; also a cotton-compress with a ten-hour capacity of 1000 bales and three others with a total capacity of 1400 bales. The wharf is 120 feet wide on the first floor and 100 feet on the second, with a total length of 2000 feet. It is of reinforced concrete and steel, on a foundation of nearly 10,000 creosoted piles, in clusters 20 feet between centers, filled in with 2,000,000 cubic yards of river-sand. Along its full front, there is an apron-wharf carrying two tracks, and depressed tracks in the warehouses permit of unloading freight from cars within reach of the ship's tackle. The warehouse-sheds are roofed in spans of 35 and 45 feet. Motors, traveling on runways, transfer articles between the compartments and to the wharf-front. There are also large receiving and sorting yards. The reduction effected in the cost of transportation is estimated at 40 per cent.

Freight Sorting Yards. Gravity Switching Yards

The increasing production of commodities consequent upon industrial development in the United States caused a gradual tendency to congestion of traffic upon the principal railway thoroughfares, which called for improvement in methods of concentration and distribution of the freight-equipment employed in such service. It became imperative that these operations should be carried on elsewhere than on the sidings required for the normal movement of trains, and certain principles became recognized in the construction of switching-yards, or sorting-yards.

It is obvious that the breaking-up and the making-up of trains should not be undertaken on the running-tracks nor by crossing from one side of such tracks to the other; but that operations of this kind should be carried on apart, and away from interference with regular train-service. With this separation of trackage, more efficient track-plans were devised for the distribution of cars as a train is broken up, and for their concentration in other trains according to their respective destinations. A series of sidings was arranged in the form of a parallelogram, and known as a "gridiron," on which arriving trains were placed on one set of tracks and the cars in them were distributed on another set, in trains ready for departure. The approach and return tracks, connected with these parallel tracks at their ends, are known as "ladders." The usual arrangement is a receiving-yard with long tracks, a classification-yard and a departure-yard, with accessory sidings for caboose-cars, for crippled cars, for live-stock and for icing perishables; with conveniently situated roundhouses and repair-shops.

The forwarding of cars in transit was greatly facilitated by such track-arrangements, but there was a loss of time in the double movement of the switching-locomotives; first in pushing each car, or cut of cars, into its appropriate track and then in backing out with the remainder of the train as yet undistributed. The unnecessary movement of this part of the train was prevented by the introduction of the "poling-track," parallel with the "body-track," on which the train is placed for distribution. The switching-locomotive has a pole attached to the breast-beam, which is placed in contact with a "poling-pocket" on the corner of the last car in the cut. Each cut is then pushed into its proper track without disturbing the remainder of the train. A safer method has been provided by the intervention, ahead of the locomotive, of a flat car specially equipped with four poles; two on each side that can be used in opposite directions.

On the poling plan, the switcher works close to the front of the train, where the clearance of each track can be more distinctly seen and signals received at shorter range than at the rear of a long train, which is an advantage in thick weather. The operation of a poling-yard is thought to be severe on equipment, on account of the necessarily quick and heavy starting and reversing movements. Where the tracks could be laid on a descending grade, this objection has been obviated; for the train could be gradually dropped ahead by the brakes, as each cut was removed. A grade of at least 0.4 per cent. was required and, in very cold weather, even an 0.8 per cent. grade was not found objectionable.[1]

The advantage of distributing cars on a descending-grade was further utilized in their classification solely by gravity. The switching-locomotive was replaced at the rear of the train and pushed it to the summit of the grade by successive movements, as each cut of cars was released; so that there was no unnecessary reverse-movement of either the train or the locomotive. In the approach to the freight-terminals of the London & Northwestern Railway at Liverpool, there was an inclined plane at Edge

[1] In such a yard for distributing coal-trains, 1428 loads were passed through in 10 hours, 20 minutes; an average of 138 cars per hour. "Freight Terminals," J. A. Droege, p. 62.

Hill belonging to the early period of railway construction, upon which the custom originated of cutting each coal-wagon loose at the top of the plane and "riding" it down to the foot and into a siding; its speed being controlled by a hand-brake or by a skid.

At Edge Hill, in 1873, a gravity switching-yard was laid out on the gridiron plan, and the "push-and-pull" process was abandoned. From 2000 to 2500 wagons are collected here daily from the several receiving-stations in Liverpool and are sorted on a group of twenty-four storage-sidings, from which they are re-distributed on a set of shorter tracks in station-order for departure. There are but few places where the opportunity is afforded, as at Edge Hill, for sorting by gravity from a higher to a lower level. One was provided near Dresden, as early as 1846, by making a fill at the upper end, seventy feet high. This yard is 1½ miles long and half a mile wide. There is another near St. Etienne, on the Paris, Lyons & Mediterranean Railway, dating from 1863. On the Pennsylvania Railroad lines, there are such gravity-yards at Greenville, N. J., Sheridan, Pa. and Logansport, Ind.; and on the Norfolk & Western Railway at Bluefield, W. Va.[1]

The obvious merits of gravity-switching were limited by local conditions until its fundamental principle was artificially reproduced in the "summit" yard, by the intervention of a double inclined-plane — a "saddle-back" or "hump" in railway parlance — between the reception-tracks and the classification-tracks. Over this hump, the trains were pushed and the cars distributed, as in the gravity-yards operated under natural conditions. The first summit-yard in the United States was constructed in March, 1883, on the Pennsylvania Railroad, near Greensburg, Pa. In the United States, in 1910, out of 510 classification-yards, 82 were hump-yards. The most extensive yard is at Gardenville, N. Y., on the New York Central Railroad for traffic in the Buffalo territory, which has capacity for 21,000 cars.[2]

A sorting-yard should be carefully designed with reference to the character and volume of the traffic to be handled there, for it is difficult to remedy mistakes resulting in unnecessary switching. By comparatively slight changes in the track-arrangement, the service of a yard-locomotive and crew may be dispensed with at an accompanying saving of about $14,000 per annum, equivalent to the interest at five per cent. on over $275,000. The receiving-yard should lead directly into the classification-yard and should have track-capacity for the trains arriving during one hour of maximum traffic. The tracks should each accommodate the longest train and none of them should be less than half the length of that train.

[1] For gravity-yards on Norfolk & Western Railway, see Appendix V, Table XXII, and for sorting-yards in United States and in Continental Europe, see Table XXIII.

[2] See Appendix V, Table XXIV. For statistics of principal gravity-yards in the United States, see "Freight Terminals," Droege, pp. 74, 112.

The arrangement of tracks in the classification-yard should conform to the purpose of classification. For classification by districts, the cars are to be arranged in station-order for delivery. For arrangement as to commodities, a further classification is required on other tracks. The capacity of the yard is determined by the average number of cars to be forwarded daily to the several districts, with allowance for emergencies. The minimum capacity of any hump-yard in this country is stated at ten trains of 65 cars each in 24 hours, with maximum hourly arrival of three trains, and provision for classification at the rate of eighty cuts per hour. Preferably, there should not be more than twenty tracks in one set. A greater number requires longer ladder-tracks and correspondingly unnecessary length of switching-movements. By the use of a "V" ladder, with leads to a gridiron on each side of it, a maximum number of 36 tracks may be conveniently served. A departure-yard should be so arranged that cars from the classification-tracks can be moved directly into its storage-tracks ready for the roads. Where entire trains are held for orders, separate tracks should be provided for their storage, so as not to interfere with the switching-service.

Body-tracks, for holding trains, should be spaced 11½ to 13 feet between centers and, if possible, without curves. At intervals of five tracks, there should be a wider space to provide for drainage and for piling track-material. Ladder-tracks should be 15 feet between centers, to give room for throwing switches; and no yard-frog should be of a less angle than the No. 7 frog of 8° 10′. There should also be a clear space of at least 15 feet between the yard-tracks and the running-tracks to afford room for signal-posts and for water-columns. The track-scales should be in the lead to the classification-tracks, with "dead" rails for their protection. Icing-tracks should be placed between the receiving and the classification yards. Tracks for caboose-cars should be situated where they can be readily shifted from an arriving-train, and dropped to the rear of a train departing in the opposite direction.

"Bad-order" tracks should be so connected with the receiving-yard that cars may be placed on them as they are being classified. These tracks should also be ready of access to the repair-tracks. The repair-tracks should be in two sections, with switches locked at the end of each section. As one section is filled, the switch-key should be held by the foreman of car-repairs until the work on the cars in that section has been completed and the workmen have been transferred to the other section. Repair-tracks should be of a length sufficient to hold fifteen cars with space between the cars for working upon them. The tracks should be in pairs, 16 feet between centers and 25 feet between each pair for handling materials. A narrow-gauge track in this space should be connected by a turntable with a cross-track to the material-yard and the supply-stores. A track should be reserved for light repairs and wheel-renewals to fast-freight and stock trains.

Approach-tracks should be provided at the entrance to a freight-yard with an interlocking-plant and telephone-connection, in order that arriving-trains may be removed promptly from the main line. There should be a similar arrangement at the outlet of the yard for departing-trains. Their departure will be facilitated by testing the brakes before the road-locomotive is attached. For this purpose, a line of piping should be run across the yard from an air-compressor, with a hose-connection between each pair of tracks. The yard-master's office should be established at a central point and at a height giving a good view of the yard. There should be a building adjacent, with rooms for the yardmen with wire-screened lockers for their clothing and, in some comparatively quiet spot, a rest room for the road-crews.

With a natural incline, all trains must enter the yard at the upper level. In the case of trains from the other direction, this may require a useless journey of several miles, which can be avoided in the hump-yard by having a hump for each direction. The gradient on the descent should be gradually decreased so that the cars will stop in the classification-yard. The practice in Europe is a gradient of 20 to 25 feet per 1000, or of 2 per cent. to 2.5 per cent. from the top of the hump, changing to 15 feet per 1000 at about 150 feet from the entrance to the sorting-tracks, which have a gradient of five feet per 1000. In the United States, with cars of heavier loading-capacity, the initial grade at the summit varies from one per cent., with a fall of 0.7 feet in 70, to a 3.9 per cent. grade with a fall of 5.8 feet in 150. In the former case, there is a further fall of 5.25 feet in 300, or of 1.75 per cent., to the bottom of the ladder, with a velocity at the foot of the initial grade of 4 miles an hour, and, at the bottom of the ladder, of 14.6 miles an hour. In the latter case, the further fall is 13.8 feet in 1500, or 0.92 per cent., with a velocity at the foot of the initial grade of 12.2 miles an hour and of 27 miles an hour at the bottom of the ladder. In the Chicago Clearing Yard, the ascent and descent of the gravity-lead is accomplished in about 4500 feet. The ascent is on a 1.25 per cent. grade for 1800 feet to an elevation of 22 feet. The descent of 2700 feet is for a short distance on a one per cent. grade and thereafter 0.9 per cent. The velocity at the foot of the initial grade is 10.9 miles an hour and at 2500 feet it is 28.5 miles an hour in the summer.[1]

The wide variation of practice in this important matter results from difference in local conditions and in the character of the traffic. The effect of the weather is also distinctly perceptible in accelerating or retarding the descent of cars on the incline. At Altoona, Pa., in the severe winter of 1903–1904, cars did not run to the end of the yard, although the initial grade from the summit was 2.55 per cent. and from its foot there was a grade of 0.7 per cent., well into the yard. The summit was raised on

[1] For additional statistics on this subject, see "Freight Terminals," Droege, p. 74.

crib-work to a grade of four per cent. for 200 feet to meet this emergency. A mechanical hump was devised on the Pennsylvania Lines for scale-tracks, which is speedily adjustable by jack-screws through a range of five inches, with a corresponding range in the gradient from one to four per cent.

Gravity-yards have been still further developed with interlocking-mechanism controlled from a cabin at the summit, in which the successive movements of the switches are indicated on a miniature-plan of the tracks, which is electrically connected with the interlocking-apparatus. The Chicago Clearing Yard was thus constructed, some fourteen years ago, at a cost of $8,000,000. It is now operated as a union freight-terminal by twelve railroad companies, and serves physically the same purpose with the traffic that a railway clearing-house does in collecting and distributing the revenues accruing from that traffic.[1]

Experience in lighting freight-yards for night-work has led to the substitution of pole-lights for tower-lights. The high-voltage, mercury-vapor lamp on a tower 90 feet high, is an expensive installation, which can not be as readily changed to suit changes in the lay-out of a yard, as can be done with lighting-units on poles 35 feet high and from 100 to 200 feet apart, with spot-lights for switches on the ladder-tracks.

Where practicable, yards for traffic in opposite directions should not be located beside each other, but should be connected at their ends and on opposite sides of the running-tracks, and there should be repair-shops and roundhouses near their junction; also a separate entrance for the yard-locomotives to the coal and water supplies, to avoid delay to them from road-locomotives standing on the roundhouse tracks.[2]

[1] An electro-pneumatic mechanism was installed on the Chesapeake & Ohio Railway at Russell, Ky., at a cost of $14,000. It operates 21 switches, with an increase in the daily average from 851 to 1139 cars and a saving of $645 in the monthly cost of operation.

[2] NOTES ON GRAVITY-YARDS

In a gravity-yard used largely for mineral-traffic, the maximum number of trains arriving in one hour was seven, and in twenty-four hours, thirty-three. Average number of cars in a train fifty; and over the hump, sixty-eight cars with 3800 tons of load. Hump in actual operation, 15¼ hours per day. Switches operated by compressed air. Classifying capacity, as follows:

Hours	Eastbound Cuts	Cars	Westbound Cuts	Cars
1	81		108	
5	291		389	
10	580	1,318	688	1,396
24	900	2,151	1,205	2,488

Delivery-yards

The importance of having delivery-yards well planned and constructed is shown by the magnitude of some of them. The team-delivery yard in Providence, R. I., occupies 21.8 acres and has capacity for 675 cars, with 458 accessible to teams.[1] Tracks for team-delivery should not hold over fifteen cars each. They should be stub-tracks, ending against the main drive-way and laid in pairs, 12 feet between centers, with a 50-foot roadway between each pair, to give room for teams to back up to the car-doors. Experience has shown that twenty-five cars for team-delivery will occupy about an acre. The driveways should be well paved and drained, and accessible to wagon-scales. Track-scales should be on or near the lead into the yard, and also cranes for handling heavy articles. Where there is much of such traffic, the crane should be operated by power, and cover several tracks with a bridge. An incline at the end of one of the team-tracks is convenient for loading vehicles on flat-cars.

The planning for handling live-stock on an extensive scale requires specific treatment to meet local conditions. Pens for loading and unloading in a small way, are usually of rude construction. A more important matter, from the roadway point of view, is the arrangement for detraining and reloading stock in transit. For this purpose it is advisable that the pens should be ranged along a siding of sufficient length to hold a complete train; as the shock in switching it in parts, causes injury to the animals and is a foundation for annoying damage-claims. There should be a runway the full length of the pens, fenced on the track side, and portable chutes for access to the upper deck of double-deck cars.

Passenger-yard Tracks

A different arrangement of tracks is required for the temporary storage of passenger-cars while they are being prepared for re-assembling in trains. The "coach-yard," as it is called, should be conveniently adjacent to the train-shed, so that cars may be speedily taken from, or added to, trains as may be required. There should be no dead-end tracks; it is necessary, also, to have either a turntable or a "Y" track for turning certain cars,

A series of switching-tests was made by Mr. C. L. Bardo, with a train of 60 cars in 50 cuts with the following results:

	Mode of Switching		
	Tail	Pole	Summit
Time consumed	2 hours	1¼ hours	Half an hour
Distance traveled . . .	24,750 ft.	24,750 ft.	6,000 feet

[1] "Freight Terminals," Droege, p. 183.

drop-pits for inspecting trucks, tracks for making up trains and other tracks for storing surplus equipment.

The tracks for making up trains should be long enough to stand two trains, say about 1050 feet. The wash-tracks should be spaced alternately 16 feet and 25 feet between centers, with platforms on a level with the rails. The wider platforms are covered by an umbrella-shed extended over the lower roofs of the cars. The storage-tracks need only be 14 feet between centers. The tracks for the wheel-pits should hold five cars, with 25 feet between track-centers. The wash-tracks should be piped for compressed-air, steam, water and gas, with plugs every 100 feet, and with connections for electric current. There should be a carpet-shed with platforms 15 feet by 75 feet and four feet above the ground, with a vacuum cleaning apparatus. Connected with the yard, there should be provided store-rooms for Pullman bedding and linen, for carpets and curtains, for plumbers', painters', carpenters' and air-brake materials, and for commissary-stores and accompanying offices, also for ice, oil and waste.[1]

The arrangements for the reception and delivery of miscellaneous freight at a local station vary materially from those for handling cars in trains at a transfer-point. Such arrangements also differ with the volume and character of the principal business done at a station. There must be tracks with access from the street to transfer commodities directly between the cars and wagons; facilities for handling, feeding and watering live-stock, and tracks available for switching without interference with the running-tracks. Industries dealing in bulk-freight gather around such stations and demand tracks for direct transfer. At important stations, overhead cranes usually span one or more tracks and a driveway. The bridge may be fixed, or move on an elevated track, or on towers moving on surface-tracks. Traveling electric cranes are in use of 40 to 50 tons' capacity, with auxiliary hoists of 5 to 7½ tons' capacity for light weights. The location and plan of the freight-warehouse should accord with the neighboring streets and will probably dominate the general lay-out of the yard-tracks.

FREIGHT HOUSES. FREIGHT HANDLING. WAREHOUSES

Freight-houses were formerly built with a receiving and a delivery platform under the same roof and two or more tracks between them. Now, there are separate buildings for inbound and for outbound freight with several tracks between them and platforms on the outer sides accessible

[1] The coach-yard at the Union Station, St. Louis, has a capacity for 665 cars, allowing 80 feet to each car, and is to be enlarged to a capacity of 1071 cars. The Sunny-side yard at Long Island City covers a tract two miles long and 1500 feet wide, with capacity for 340 Pullman cars, 375 coaches and 700 motor-cars. The ladder-tracks are made continuous by loops. During 24 hours, the maximum number of cars handled at this yard has reached 556, with 450 cars on the tracks at one time. "Passenger Terminals," p. 241.

for wagons. The spacing for the doors on the track-side should be adjusted for cars of standard length when coupled together, and cars standing on outer tracks parallel with and close to the house-track can be reached from the house directly through the doors of cars on the intermediate tracks. Platforms for street-delivery should be of ample width for the temporary storage of goods. The platform on the house-track and those between the tracks for transferring directly from one car to another should be wide enough for loaded trucks to pass each other readily and all platforms should have roof-protection. The platform-floors should be not less than seven feet from the center of a siding and there should be a clearance of 16 feet from rail to eaves of the building.

The house for outbound freight should not be over 30 feet in width, in order to diminish the truck-haul between the receiving-door and the car-door. The scales should be placed near the receiving-doors with the scale-beam against the wall. The house for inbound freight should be wider, as more storage-room is required. A slight slope in the house-floor in the direction of the trucking, facilitates the work. The door-jambs should be protected and the edge of the team-platform by a timber wheel-stop. Part of the house for inbound freight is usually set apart for handling small lots in transit, but at transfer-stations this requires separate accommodations. At one transfer-station, 32 cars are brought to the platform on each trip, and their contents are distributed into 135 cars standing on nine tracks. The transfer-platform at Waverly, N. J., on the Pennsylvania Railroad is 1000 feet in length, with placing-room for 196 cars and an average outward movement of 230 car-loads daily.

The elevation of tracks entering large cities has led to the construction of freight-houses with tracks on the second floor. The desire to utilize the valuable area thus occupied, has likewise induced the addition of several stories for storage-purposes, with special regard to economy and dispatch in moving freight between the different floors and to its storage and preservation from loss and damage. These houses are built in fire-proof compartments with automatic sprinklers for extinguishing fires. The floors are of creosoted yellow-pine resting on sleepers imbedded in sand, tamped-clay or ballast and, for protection in trucking, are covered with tongued-and-grooved maple flooring, 8-inch by $\frac{7}{8}$-inch.

The reduction of labor with hand-trucks is an important consideration, apart from the lessening of contingent damage to freight. The cost of transferring a car-load of miscellaneous goods from the car-door to the delivery-platform may, on an average, equal the ton-rate for 200 miles; and it has been estimated that the average haul in trucking increases 27.8 feet for each additional hundred feet in the length of the house. Much attention is being given to shortening this haul and to accelerating the movement by the use of capacious trucks operated by electricity; or by such mechanical appliances as horizontal conveyors (either roller, chain or platform), or by hydraulic or electric elevators, with a speed of 20 feet per minute. Overhead cranes are also used in warehouses and, in some instances, the telferage system of steel runways, on which are operated electric travelers, with hoists. These overhead appliances require a considerable addition to the ordinary height of walls, to clear the work on the floor, which adds materially to the cost of the building.

A freight-warehouse recently completed for the Lehigh Valley Railroad at Buffalo, is 577 feet long and 60 feet wide. It is built of concrete and is divided into three sections by fire-walls with automatic steel doors, and with roof-trusses spanning the entire building. The interior is lighted through continuous wire-glass windows over the doors, and artificially by three 200-watt lights in each section. There are nine scales in the freight-house, each of 3500 pounds' capacity. On the track-side there is a concrete platform, 10 feet wide, with a canopy roof. The station is provided with a 40-ton electric crane, operating through a longitudinal distance of 148 feet and capable of serving four cars at a time.[1]

Station Accessories. Scales

On European roads, a clearance-frame for loaded open cars and a crane operated by hand are usually to be found at every station; and the use of such station-appliances is becoming more general in the United States. This is also true as to track-scales which came into use about 1850. The importance of having such scales substantially constructed, and the necessity for careful maintenance, in order to preserve their accuracy, is evinced by the attention that has been given to these matters by the American Railway Association. Its rules on the subject were revised at great length June 26, 1916. They include the selection, installation and location of scales, and their maintenance and use. The requirements for track-scales relate to their capacity and length, to cover the maximum capacity and wheel-base of the heaviest loaded cars, and their suitability for weighing cars either at rest or in motion.

For verification, a scale should be capable of adjustment to within half a pound per 1000 pounds, when new, and should be considered as inaccurate when it can not be adjusted to within two pounds per 1000 pounds. When cars are to be weighed in motion, the speed should not exceed four miles an hour; each car to be entirely alone on the scale for three seconds. There should not be less than 50 feet of tangent-track at each end of the scale-rails. The foundation should either be of concrete or of cut-stone laid in concrete, and the walls should be extended to support the approaches for a full rail-length at each end of the scale-pit. An efficient transfer-rail should be introduced to prevent the impact of cars at the joint between the approaches and the scale-rails. Both of these

[1] "New Lehigh Valley Railroad Station at Buffalo." — Railway Age Gazette, Sept. 15, 1916.

rails should be securely anchored to prevent creeping, and should be kept in proper line and surface. The scale-pits should be water-proof and be drained into a cistern. They should be properly lighted for cleaning and testing.

Locomotives that are not to be weighed, should be passed over the dead-rails. All scale-pits should be cleaned at least twice a month and tested every three months, preferably by a test-car or by test-weights up to 10 per cent. of their capacity. The test-car should weigh between 30,000 and 60,000 pounds for general tests. The United States Bureau of Standards has provided traveling-equipment for testing master-scales which, by arrangement with the American Railway Association, is moved over the entire railway system annually in accordance with a pre-determined time-table. The itinerary for 1916 provided for tests at nineteen places.

Freight-cars should be stenciled at intervals of time, in order to test the correctness of the weights originally stenciled upon them. The loss of weight, after some years of service, may seriously affect the correct billing of bulk-freight. In a lot of 1500 box-cars of 80,000 pounds' capacity, that had been in service about two years, a test of one hundred, made at random, showed that these cars were actually carrying, on an average, about 1500 pounds per car more than the billing called for. Such loss in weight occurs also in steel cars. In a lot of 1000 cars of 100,000 pounds' capacity, one-half of which had been in service for about two years, the average depreciation in weight was from 900 to 1000 pounds. There is a further loss in billing weights in drop-bottom cars from neglect to clean them out thoroughly. Under weights in billing from this cause have been found to amount to between 500 and 1000 pounds.[1]

Design of Station Buildings

In planning a freight-station, the primary consideration is economic efficiency. In planning a passenger station, the primary consideration should be social efficiency. The provisions to meet this requirement must, of course, be suited to the extent and character of the traffic. At flag-stations, a mere landing-place is frequently the only provision, yet this alone should not be deemed sufficient. There should, at least, be a shelter, walled in on the back and sides, with a bench against the wall.

At regular stations, the accommodations must vary with local conditions. At minor stations, it is practicable to house both passenger and freight business in the same building, with less expensive service and with better supervision than if they were conducted separately. A building 75 by 25 feet, with broad eaves will answer this purpose. It should be divided transversely; one-half for the freight-room and one-third for the waiting-room, with the office and baggage-room between them. The office should extend out on the platform, for giving train-orders, for displaying

[1] Association of Transportation and Accounting Officers. Minutes of Meeting, No. 11, June, 1909. Page 1526.

signals and for a better view of the tracks, with a ticket-window in the waiting-room wall. The two lavatories should be on the end-wall of the waiting-room. At such stations, it is advisable to provide dwelling-accommodations for the station-agent, that he may be on hand in an emergency. There should be a short stub-track and trucking-platform at the end of the house, with a ramp leading to the freight-room, as well as a door at the front.

For places with sufficient traffic to require separate accommodations, the passenger-station can be designed on standard floor-plans, with dimensions corresponding to the volume of business, and the elevations varied architecturally. With a frontage of 50 to 75 feet and a width of 20 to 25 feet, half of the floor-space should be given to the general waiting-room; and, with a frontage of 100 to 125 feet and a width of 30 to 40 feet, about two-thirds. The agent's office and the baggage-room could be at one end of the building. The women's room could occupy the front at the other end with a smoking-room at the rear and the two lavatories between them.

The general waiting-room should have an opening into the baggage-room, with hard-wood benches, having arms, at intervals, to separate the occupants in groups. These benches should be fixed to the floor by fastenings easily removed for washing the floors, which should be preferably of granolithic or similar material, as well as the outer-platform floors. If the interior walls above the wainscot are of rough plaster, they can not be disfigured by scrawls or scratches; and a whitened ceiling will aid the illumination. In a cold climate, hot-water heating is better than stoves, with radiators back of the benches, and the heater under observation in the baggage-room. The ground-platform should have a roof-covering and be not less than 15 feet in width, with a slight pitch toward the edge, which should be 5½ feet from the center of the track, with the supporting posts 7 feet farther in. The end-extensions of the platform should be protected by an umbrella-shed. Near each end, station-signs in large lettering should be conspicuously placed and illuminated. Station-buildings of this character were formerly framed structures but, of recent years, concrete construction is in more general use.[1] At junction-points, the floor-plan of the station-building must conform to the lay-out of the tracks, and more ample space is required in the waiting-rooms. Provision must also be made for refreshment-rooms, news-stands and sanitary requirements for persons waiting between trains. Arm-chairs and rocking-chairs in the women's waiting-room are appreciated by weary women with children.

On double-track lines, consideration must be given to the safe transfer of passengers between the waiting-rooms and the trains. In some cases, a covered platform is built on the opposite side of the line, for access to

[1] For standard plans recommended by the American Railway Engineering Association, see "Passenger Terminals," J. S. Droege, p. 254.

trains on that side. Where this plan is adopted, there should be a fence between the tracks, for the length of the platform, with a crossing provided in front of the waiting-room through a gate, which should be locked when trains are due. Where trains are so frequent as to render this arrangement hazardous, the tracks should be crossed either by an overhead passageway or by a subway. On a four-track line, to reach the middle tracks there must be width between them for an island-platform, accessible from the crossways.

The terminals of all lines entering a city should be concentrated in a union-station. This is usually a problem difficult of a satisfactory solution; and especially in cities on the sea coast and the Great Lakes, where the railway lines radiate from stations widely separated by thronged streets and valuable real-estate. Yet union-stations are obviously so necessary to the general welfare that great efforts have been made to provide them. It is not essential to the convenience of the traveling public that a union-station should be located adjacent to the heart of a great city. The area for its efficient operation can there be acquired only at an enormous cost. If it be situated in the suburbs, means are soon provided for access to it locally. On a single-track line there should be a double-track approach to the station-tracks in a large station, with a cross-over, to avoid obstruction to train-movements. Where there are many station-tracks, these approach-tracks should be again divided into "throat-tracks"; one for every two to six station-tracks.[1]

For practical purposes, it is preferable that trains should be able to pass through a station without reversing their direction. In a through-station, the currents of passengers are more easily kept apart, each with its own station-facilities; communication between them being provided either below or above the tracks. This arrangement is often practicable for a union-station where the lines of railway pass by it, instead of terminating there. But where the lines of railway approach the station from widely different directions and terminate there, the only practicable plan is that of a head-house with dead-end tracks. Such a terminal requires a reverse-movement of every train that enters it.

In European countries, where the locomotives and carriages are shorter and lighter than in this country, some of the terminals are equipped at the dead-ends with electrically-operated transfer-tables. At the St. Louis Union Station, trains back into the station over "Y" tracks. Plans have been devised for connecting the dead-ends by a loop. This requires considerable radial space beyond them for a loop with 180° of curvature, and can only be adopted where the tracks are on a level beneath the waiting-rooms. In fact, such a plan is of little value either for long-distance trains,

[1] In the Union Station at St. Louis, there are two sets of throat-tracks of three each to thirty-two station-tracks. The South Station, Boston, has eight throat-tracks to twenty-eight station-tracks.

which must be broken up for the cars to be cleansed and provided with water and fuel, and the storage-batteries recharged, or for suburban-service where cars with electric tractors need not be reversed.

Train-service in a busy station may be accelerated by the interposition of three tracks between two platforms of sufficient length for each to hold two trains, with a double cross-over, or "scissors-crossing," midway, and the middle track used as a running-track. This plan is not favored in the United States on account of the normal length of trains, which would require a platform of 500 to 900 feet in length to accommodate two trains and to allow between them 160 to 175 feet for the cross-over. The height of ground-platforms in the United States is about ten inches above the rails. In European countries, except in Switzerland, the platforms are on a level with the side-doors in the carriages. This arrangement admits of more speedy departures with less effort to passengers, also of convenient access to the piping under the platform; but it requires the use of lift-decks on all cars with end-platforms, as in vestibuled cars. Track-platforms should be amply lighted with lamps on several separate circuits, so that a part of them can be cut out when the platforms are not in use. Where there are frequent train-movements, the service will be expedited, and with less annoyance to passengers, if it be practicable to have a separate platform for baggage-trucks between each pair of running-tracks; with a ramp to a crossing at the outer end, where the platforms are elevated.

Union and Terminal Stations

The problems connected with the planning of a union-station vary profoundly with its environment. In Boston, the lines approaching the city from one direction were concentrated in the North Station, and those from the other direction in the South Station. At St. Louis, the concentration was rendered more complete by the construction of two bridges over the Mississippi River. The immense area covered by the city of Chicago has proved an insuperable barrier to the establishment of a single union-station, but there is a gradual concentration of lines in the same terminal which have a common interest in passenger-traffic or which are conveniently located for such a purpose. The Union Station in Washington, D. C., is, in many respects, a model for a complete union-station as to track and platform arrangements, in its accessibility to waiting-rooms and exits, in its relation to environment, and in its architectural effect.

In New York City, there is a partial development of two union-stations, as in Boston. The Grand Central Station accommodates the New York Central, the Harlem and the New Haven lines, and the Pennsylvania Railroad Station provides also for the Long Island Railroad trains, and is now also accessible for trains from the New Haven lines, by the completion of the New York Connecting Railroad over the entrances to Long Island Sound. This station is virtually a "through" station, made so by the depression of its tracks. If its capacity were greater, it would not be a difficult engineering problem to make it a union-station for all lines terminating on the opposite shore of Hudson River.[1] As with plans for terminal facilities for freight-traffic, those for passenger-terminals have not always been conceived with sufficient forecast. In New York City, the Grand Central Station has been both enlarged and reconstructed within a period of forty years. The new Pennsylvania Railroad Station had been opened but a few days when it was found necessary to remodel the facilities for Long Island Railroad trains. Even in smaller cities, there has been the same experience, with the demand for more extensive premises and more pretentious structures. In Philadelphia, the Pennsylvania Railroad Company found it necessary to remove its terminal station from the through route between the East and the West and, at great expense, to bring it into the heart of the city, in order to accommodate its suburban traffic.

The conditions as to terminal passenger-stations in London are controlled by the original location of the lines as they entered the metropolis. These are eight in number and they severally occupy independent terminals, though the different lines are connected with each other by a maze of suburban-tracks. Little attention has been given to external architectural effect, and the accommodations for the convenience of passengers do not compare favorably with those provided in the great stations in Continental Europe and in the United States. They are, however, well arranged for expeditious train-service and for handling a large number of passengers daily.[2]

The planning of passenger-stations culminates in the design and construction of terminals where provision is to be made on an extensive scale for the receipt and disposition of throngs of travelers, with due regard to their safety, convenience and comfort between the trains and the station portals. A passenger terminal station in a great city belongs in the class of public buildings, and deserves monumental architectural treatment. Yet its practical purpose is to provide comfortable and convenient facilities for receiving and dispatching travelers. The use of classical motives and principles of design which prevail in buildings of a public character, should not affect the dimensions or terminal arrangements of a terminal

[1] For a description of the Pennsylvania Railroad Station, see Appendix V, Note XXVI.

[2] The Liverpool Street Station of the Great Eastern Railway has a traffic averaging 176,000 persons a day. The St. Lazare Station of the Western Railway in Paris is the largest station in Europe, with a traffic, in 1909, of 52,800,000 passengers and a daily average of 144,000, which, in the summer, exceeds 200,000. The daily transfer of passengers from one train to another averages 20,000. The daily average in the Grand Central Station, New York City, is about 60,000 passengers; and in the Pennsylvania Railroad Station, about 47,000. In the South Station, Boston, it is about 105,000.

station, as regards its economic and social efficiency; nor should its architectural treatment ignore or conceal the features which indicate its purpose. Classical façades may diminish the openings for air and light and affect the proper internal division of rooms. Sculptural groups are hidden at lofty heights and their existence is forgotten. Gaudy mural decoration is unnoticed by the passing throngs, and becomes obscured by dust and faded in the sunlight. There should be, preferably, a harmonious color treatment of broad surfaces, emphasizing the lights and shadows of the architectural details. Prominence should be given to entrances and exits and to the location of the accessories necessary for the convenience and comfort of passengers. There is no rational objection to the space above the waiting-rooms being utilized to a suitable height for offices; thereby minimizing the expense for the maintenance of a structure which is otherwise an unproductive charge upon railway revenues.

The traffic at such terminal stations is either suburban or long-distance, and the difference in the corresponding requirements is fundamental. The chief desire of dwellers in the suburban zone is to pass through the station expeditiously and with the least possible inconvenience. They move in large bodies, with little hand-baggage and less heavy luggage. They are commuters, and seldom have occasion to visit ticket-offices. They have no need of other conveniences than lavatories, for they do not linger in waiting-rooms but want ready access to the street-cars with protection from the weather. Long-distance travelers have other requirements. They have more need of ticket-offices and Pullman reservations, of telephone-booths and telegraph-offices. There is yet another class of travelers who neither begin nor end their journeys at these terminals, but who pass through them on their way to another destination.[1] These requirements, with proper ventilation, sanitation, lighting and heating, include the primary conditions for social efficiency in a large terminal passenger-station.

It is further advisable to separate the arriving and departing throngs of passengers. To maintain the even flow of these opposing currents, there should be no intervening interruption to break their steady march in a straight line and on a uniform gradient between the train platforms and the station portals. This requirement is fulfilled by a vaulted concourse directly facing the train-shed, with the waiting-rooms, ticket-offices and accessory conveniences ranged around it and lighted through the exterior walls or from the ceiling.[2] The station-signs in the con-

[1] The Union Station recently built in Kansas City is probably the largest station in the world that is devoted almost entirely to this class of passenger-traffic. For a description of this station, see Appendix V, Note XXVIII.

[2] The principal concourse in the Grand Central Station has an area of 81,122 square feet; that in the Union Station at Washington has an area of 98,800 square feet and is supposed to be the largest unbroken floor space in any room in the world; that in the Pennsylvania Railroad Station in New York City has a broken floor-space of 131,400 square feet.

course should be well arranged and of good size, and the track-numbers and train-designations conspicuous and distinct for the instant and accurate guidance of the hurrying passengers. The coloring of the extensive wall and ceiling surfaces in a concourse affects the illumination. A white surface reflects 50 per cent. of the intensity of the light striking it, red or dark green but 15 per cent. and dark brown but 2½ per cent. Artificial lights should be so distributed as to give a uniform illumination over the floor-area. Electric lights should be shielded by ground-glass or opalescent shades, and heavy shadows avoided.

Train Sheds

Passenger-stations in large cities require special treatment to suit each environment, physically and socially. The buildings may be of greater dimensions, more architecturally ornate, or more diversified in arrangement, but there are no additional principles in which they differ, as a class, from other station-structures, except where the track and platform lay-out is amplified and roofed over. The train-shed proper is usually a lofty vault of arched iron ribs covered with glass and sometimes extends over as many as thirty-two tracks.[1] It is an imposing but costly structure, resonant with conflict of noises, the interior stifling at times with coal-smoke which settles upon the glass overhead, dimming the light and corroding the framework. The artificial lighting is necessarily concentrated at an elevation at which much of the illumination is useless. The air is draughty in winter and oppressive in summer, and the overhead structure requires frequent attention, under difficult conditions, to keep it in repair. These defects in the vaulted train-shed affect more or less the conditions in the adjacent station-building.

The objections to a vaulted train-shed have led to the introduction of individual sheds over the several train-platforms, known as "umbrella" sheds. This type of train-shed, supported by a central line of posts, has the merits of cheaper construction, better ventilation and easier illumination; but with the disadvantage of less protection from bad weather. The "butterfly" shed is a variation of the umbrella-shed, with the pitch of the roof reversed to form a midway gutter, drained through the central posts. It therefore protects passengers from the drip at the eaves when entering or leaving the train, and gives better light and ventilation when several trains are at the platforms.

The butterfly shed was further developed by Lincoln Bush, in a design installed in 1905 at the Lackawanna Terminal in Hoboken. In the "Bush" shed, the inverted eaves of the butterfly shed are extended to connect over the center-line of the intervening track in a series of low vaults. The peculiar feature of this type of shed is the introduction of a duct along each vault over the center-line of the track, so near to the top of the loco-

[1] The shed of the South Station, Boston, covers 28 tracks.

motive stack that the smoke escapes directly into the open air. The trains and platforms are entirely protected from the weather and the farther sides are also inclosed. The shed is lighted by continuous skylights in the vaulting. The Bush shed at the Jersey City Terminal of the Central Railroad of New Jersey, completed in 1914, covers 20 tracks and 7.07 acres. There are two tracks between platforms under a vault, with a smoke-duct over each track and three rows of skylights in each vault; the middle row being in a low monitor roof. The rainfall is carried through the central line of posts into an outfall drain. There are now eleven sheds of this type in America.[1]

Ferry Terminals

The isolation of great cities from railroad communication by water-courses, too broad to be readily spanned, has caused the construction of railroad ferry-terminals. Terminals of this character, on an extensive scale, are situated on the western shore of Hudson River at New York and, at San Francisco, on the opposite shore of the bay. A distinctive feature of some of these terminals is the location of the waiting-rooms and accessory conveniences for passengers in the second story of the building to afford easy communication with the upper-deck cabins of the ferry-boats. The terminal buildings of recent construction have steel frames sheathed with copper. They rest on piling, and the roof projects over the slips sufficiently to protect the passage to and from the boats. Buffer platforms are placed in the floor at the head of the slips to diminish the shock to the terminal structures from impact. As the ferries are also used for local street-traffic, driveways to the boats and passenger-accommodations are necessarily required on the ground floor, separated from the railroad terminal. A large suburban-traffic is to be provided for, in addition to the long-distance travel; also the terminal is necessarily duplicated on the city side.[2]

Special Requirements for Elevated and Depressed Tracks in Large Cities

Track-elevation through large cities necessitates special arrangements of passenger-stations. Where the environment admits of driveways on suitable gradients, the station-building may be on the same level as the tracks, or even on a somewhat lower level and connected with the train-platforms by a slight incline. If the space is not available for this plan, the station-accommodations must be at the street-level, and the several platforms reached by subways in connection with stairways and elevators or, more efficiently, by moving inclined planes or "escalators."

[1] See "Passenger Terminals," Droege, p. 40.

[2] See description of the Jersey City Terminal of the Central Railroad of New Jersey, Appendix V, Note XXVIII.

The entrance into a city by tracks below the street-surface permits of a different arrangement of station-accommodations and of an enlargement of space within the surface-area prescribed by local conditions.[1]

The additional space is obtained by extending the tracks and platforms beneath the lateral street-surface with a concourse on the same level but lighted and ventilated within the surface-area of the railroad property and connected by stairways with waiting-rooms and exits at the street-level. Such stairways should be planned to facilitate the free movement of throngs of passengers. The upward movement will average 20 to 30 persons a minute per foot of width and 18 to 25 persons downward; all moving in one direction over stairways not less than four feet in width; they should be at least twice that width for a movement both ways simultaneously. The treads should be 11 inches wide with risers $6\frac{1}{2}$ inches high, and the top and bottom steps should be brightly lighted. Where the relative levels and heights will admit of the use of inclines, or ramps, they are preferable to stairways, permitting a much more rapid movement. In the Grand Central Station, they have been introduced generally and on an extensive scale, on gradients of between three feet and eight feet to 100 feet.

The area occupied by the principal waiting-room in large terminal stations in the United States varies between 25,000 square feet in the Chicago Station of the Chicago & North Western Railway and 33,000 square feet in the Pennsylvania Railroad Station in New York City. The Liverpool-Street Station of the Great Eastern Railway in London has four waiting-rooms with a combined area of 3000 square feet. Space in baggage-rooms varies considerably: it is 27,794 square feet in the South Station, Boston; 41,683 square feet in the Union Station in Washington; 50,000 square feet in the Pennsylvania Station in New York, and 74,048 square feet in the Kansas City Union Station. The baggage-rooms in the Grand Central Station are in a separate building. The several offices for furnishing information, tickets and Pullman reservations, and for checking baggage and parcels, should be arranged in successive order adjacent to the concourse and the general waiting-room. Carriage and baggage-transfer offices, telegraph-offices and telephone-booths should also be conveniently sought in that vicinity. Refreshment-rooms should be conspicuously placed, with a clock prominently in view and notices of train departures.[2]

[1] The Pennsylvania Railroad Station in New York City has double the space of the Liverpool-Street Station of the Great Eastern Railway in London; nearly twice that of the recently-completed Leipsic terminal, the largest in Germany, and about three times that of the South Station, Boston, or of the St. Louis Union Station. For descriptions of recently-constructed terminals, see Appendix V, Notes XXV and XXVIII.

[2] Much of this information has been obtained from the work on "Passenger Terminals," by J. A. Droege, 1916; which contains illustrated descriptions of the principal passenger-stations in the United States and in Canada.

Reconstruction of Grand Central Terminal, New York City

The reconstruction of the Grand Central Station and Terminal was a remarkable engineering feat, because of the unusual conditions under which it was accomplished. The original terminal occupied about four acres. The train-shed, built in 1871, covered 15 tracks and accommodated a daily service averaging 88 trains. It was 530 feet long and 100 feet in height, with a roof of 200 feet span. In 1884, an annex was added with four additional tracks. In 1900, the station was enlarged at a cost of $2,500,000; the number of tracks was increased and three stories added to the building. The walls contained 750,000 bricks and the material in the train-shed included 1350 tons of wrought-iron, 350 tons of cast-iron, 90,000 square feet of corrugated iron and 60,000 square feet of glass; and there were 15 miles in length of piping for steam-heat. In consequence of an accident in the tunnel-approach in January, 1902, the legislature passed an act requiring trains to be operated through the tunnel by electric traction. The substitution of electricity for steam as a motive force made it possible again to reconstruct the station on a far more extensive scale.

The old structure was removed without interruption to the train-service within it. To prevent the material of the train-shed from falling upon passengers, a movable platform was operated upon wheels, beneath which there was a wooden hood shielding the platforms and covering two acres of glass. Meanwhile, the excavation for the new terminal was carried on around the old one and beneath its very foundations, perhaps at double the cost of such work under ordinary conditions. Before a part of the train-service was removed to a temporary location to make way for the excavation, there was provided a complete system of train-signals, with interlocking and electric power for train-movements; and a similar system was installed at the permanent location before the trains could be transferred back to it. The maximum number of trains in and out of the terminal was 833 in 24 hours, and the minimum was 750. The work was prosecuted night and day. The men engaged in moving the tracks had to drop their tools every few minutes for passing trains. No blasting was done in daylight hours; only between 9.30 P.M. and 6.00 A.M., when train-movements were fewest. It was only practicable to work 500 men by day and 350 at night.

The adoption of electric traction made it possible to depress the road-bed below the surface on each side of the old road-bed, beginning at the outer end of the four-track tunnel at 57th Street. Here the suburban tracks diverged and dipped gradually down to the lower level, reaching their greatest depth at about 45th Street. On this lower level, the full width of Park Avenue is utilized. By this plan, 178 per cent. of additional space was added to the terminal yards. Formerly, all trains returned empty for five miles to Mott Haven for yard-room. There were 18 trains daily to the East and North and a train every hour to or from the West. These trains had to be made up again in reverse-order and the Pullman cars placed on wired tracks for recharging their storage-batteries while they were being cleansed. All this work is now provided for within the limits of the terminal, without interference with the main tracks.

The cross-streets from 45th to 57th Street, formerly cut in two by the terminal yard, and Park Avenue, which was discontinued south of 57th Street, have now become continuous thoroughfares in a part of the city where the space covered by a ten-car train is appraised at a value of $280,-000. The terminal yards are covered over for the full width of Park Avenue, 140 feet, from 57th Street to the north end of the station-building, and a similar covering of Vanderbilt Avenue and Depew Place affords a roadway around each side of the station to a plaza in front of it at an elevation sufficient to continue Park Avenue southward by a viaduct over 42d Street. This improvement greatly diminishes the unproductive area of the railroad property by making 46 acres of it available for building sites. The construction over the tracks has been so designed that the noise of the trains beneath is not perceptible in the buildings above them.

This final reconstruction of the Grand Central Station epitomizes the development of station-service in the United States during a period of forty years. In 1910, on an average, 60,000 passengers passed through the station daily. The estimated capacity of the present station is for 70,000 passengers and 200 outbound trains per hour. During the period of reconstruction, in the eight days from August 30 to September 6, 1912, 944,000 passengers passed through the station, and 4826 trains were handled with an average delay of 21 seconds. The real-estate covered by the new terminal is valued at $50,000,000. The cost of excavation and putting up the steel to carry the train-service and the street-traffic overhead was estimated at approximately $50,000,000; and the various buildings connected with the terminal have cost between $60,000,000 and $80,000,-000 more.[1]

Difficulty of Providing for Future Growth and Expansion

Few enterprises are carried out even as fully as first conceived and still less is adequate provision made for their subsequent development, often far exceeding the original design. Even in old-settled countries, it has not been possible to furnish in advance the increased facilities needed for the volume of traffic quickly following upon the early period of railway construction, and, in a newly-settled country, this is a far more difficult matter. In no other country has this been the case to such an extent as

[1] For a description of the Grand Central Station, see Appendix V, Note XXVII.

in the United States. Even where a railroad has been constructed in accordance with the best methods at the time in vogue, it has hardly been opened for traffic before the accompanying development of the region that it serves has begun to press upon its facilities for performing that service. Villages spring up along the line and require accommodation; industries are established that demand siding-facilities. Branch-lines and extensions feed the trunk-line with increasing volume of traffic which requires heavier locomotives, and these compel the strengthening or reconstruction of the bridges. There is, also, the accompanying necessity for heavier rails and track-accessories. Increased train-service requires improvement in signal-apparatus; passing-sidings become numerous; many are lengthened as running-tracks and into stretches of double-track, until at length, whole divisions have a second track. At division-points and at interchange-junctions, cars are concentrated for classification and distribution, calling for more switching-facilities and increased yard-room, until the accompanying rise in the price of adjacent property reaches a figure which compels removal to a situation where a greater area may be available at lesser proportionate cost; while roundhouses, shops and other accessory structures must follow the switching-yards. There is a continual pressure from public opinion and by legislation for the elimination of highway-crossings at grade, and the growth of cities along the line brings with it the necessity for heavy expenditure in elevating or depressing the tracks for the protection of street-traffic.

This is the ordinary, everyday experience of the management of any railroad that is in a dividend-paying condition. There is a continual demand for the means to meet the requirements of increasing traffic and to conform to advancing standards in operation. The cost of much of such betterment is met out of operating-revenues, and that of additional equipment by equipment-trusts, until the time arrives when the required expenditure for second track and for terminal facilities can only be provided for by an increase of capital or of bonded debt. Indeed, the main railway thoroughfares in the United States have suffered so much financially, as well as in efficiency, from inability to meet the demands of increasing traffic that their managements have learned by experience that they must provide in advance for its further development. To this end, they have even undertaken the relocation of considerable portions of their lines.

The Pennsylvania Railroad Company experienced such difficulty in operation, from congestion in its terminals in and around Philadelphia, that a "cut-off," 45 miles in length, was built from Morrisville, near Trenton, N. J., to the Philadelphia Division at Glen Loch, near Downingtown, to get the through-freight trains around Philadelphia instead of passing through the terminals there. This line was built in 1889–1891 at a cost of $3,142,000, or about $70,000 per mile.

The Great Salt Lake cut-off, on the Central Pacific Railroad, is an example of relocation on a yet more extensive scale, by which many miles of heavy grades and curvatures were avoided, and which is as remarkable for rapidity of construction as for its economic efficiency.[1]

An instance of expensive relocation, merely to increase the tonnage-capacity of trains, was undertaken on the Delaware, Lackawanna & Western Railroad.[2] The reconstruction of the Erie Railroad, with the restoration of the corporation upon a firmer financial basis, has been prosecuted for thirteen years so vigorously as virtually to constitute a rehabilitation of this great system.[3]

No feature of railway reconstruction is more impressive than the conception and organization of important terminals. Inadequate forecast in providing terminal facilities has compelled subsequent expenditures, enormous in amount. This has been the usual experience wherever there is an interchange of a large volume of traffic. With the rapid expansion of railway transportation, the arrangements and undertakings for the original reception and for the final disposition of traffic at such points, and also for the intermediate exchange of cars, have become an extensive field for capital investment, and have also given rise to an important branch of roadway engineering.

Terminals differ in requirements for handling freight in bulk from what is required for handling freight in packages. In the former case, the commodity is initially stored at an elevation, from which it can be discharged by gravity. If it be grain, it is lifted by elevating-apparatus into bins. The terminal arrangements for transferring grain between rail and water at ports on the Great Lakes, are remarkable for efficiency. There is such a terminal at Buffalo with a capacity for 1,000,000 bushels. The structure is of concrete, with a dock 811 feet in length and space for docking either two large or three small vessels. It has facilities for discharging the largest cargo in ten hours, for unloading cars at the rate of 40,000 bushels an hour and for loading into cars at the same rate, while, at the same time, discharging into canal-boats at the rate of 20,000 bushels an hour.

This chapter concludes the study of the instrumentalities of railway transportation. Motive Power is the dynamic force, Rolling-stock is the medium, and Roadway is the static element of railway service. Construction by vital energy with pick and shovel, with barrows and carts, has been largely supplanted by mechanical appliances energized by steam, compressed air or electricity; steel and concrete, as materials, have been substituted for timber and stone. With these more efficient means, human intelligence has transcended the limitations prescribed by topographical environment; sinking foundations through unstable marshes, burrowing

[1] See Appendix V, Note XXIX.
[2] See Appendix V, Note XXX.
[3] Appendix V, Note XXXI.

beneath the beds of rivers, broad and deep, or crossing them in a single stretch, and even penetrating insurmountable barriers crowned with eternal ice. By comparing the railroads of half a century ago with those of to-day, we can form some conception of what has been accomplished by two successive generations of engineers in bringing our railway system into its present state of efficiency and in developing, from our natural resources, the traffic which has made us a wealthy and powerful nation.

CHAPTER VI

TRAFFIC

Preliminary Definitions

In the establishment of any standard of efficient railway operation, due consideration should be given to the characteristic features of the traffic which is properly the subject matter of Transportation. As here considered, Traffic includes all operations connected with the reception of the persons and commodities to be transported, with their delivery after arrival at destination, and with their condition intermediately.

This field of railway efficiency is not covered merely by the transportation from the point of reception to destination, but is occupied by a service for which no direct charge may be made, though it adds materially to the cost of operation. It is not measured by ton-miles, nor by passenger-miles, by locomotive-mileage nor by car-mileage. It may be considered as including the various and separate services rendered before, during and after, the actual service of transportation, in gathering together the persons and commodities to be forwarded, and in disposing of them after their arrival at destination. It also covers their proper care during transit, as well as the assessment and collection of charges for the transportation-service, and the responsibility for covering the resulting revenue into the railway treasury. With the latter exception, it is almost exclusively a service of social efficiency which, from the difficulty of defining it otherwise, may be distinguished as Traffic Efficiency.

There are three elements of Traffic Efficiency in any mode of transportation — expedition, convenience and safety. These requirements are superficially valued in the order here named; though, as safety is really the essential element, it should always be the first consideration as an evidence of traffic efficiency. This is particularly true as to passenger-traffic, in which the new slogan of "Safety First" is especially applicable. "Safety First" consists in precautions against the occurrence of accidents, in contradistinction to provisions for mitigating their consequences. When our sensibility is shocked by a thrilling newspaper account of some railway catastrophe, we jump to a conclusion as to the inefficiency of railroad management that is not sustained by a sober investigation of statistics bearing upon the subject. If it were possible to compare the meager passenger-mileage in Great Britain during the stage-coach era with the thousands of millions of railway passenger-miles that are annually accomplished in that country, the foregoing statement would find ample warrant in the comparison.

Safety in Railway Travel. Accident Statistics

There are no passenger-mile statistics in Great Britain; only passenger-journeys, exclusive of those by season-ticket holders. In 1908, out of 1,278,000,000 of such journeys, there was not a single passenger killed, and but 283 were injured. In the following year, there was one killed and 390 were injured. In the decade from 1901 to 1910, there were two years in which not a passenger was killed, one year in which but one was killed, and in the remaining seven years the proportion varied between one in 21,385,000 journeys and one in 199,758,000 journeys. The annual number of injuries to passengers in this decade varied between 283 and 1111; and the proportion as to journeys, from one in 1,176,000 to one in 4,515,000. The total number killed in the decade was 176, or about 17 persons per annum, out of an annual number of journeys varying between 1,172,000,000 and 1,306,000,000; not including the millions of journeys made by season-ticket holders. During this ten-year period, only 112 employees were killed.

As comparisons have been published of the safety of railway service in Great Britain that rather disparage railway efficiency in the United States, reference may be made to the statistical information on this subject contained in the reports of the Interstate Commerce Commission. It is preferable to consider only the period 1906–1914, both years included, as during this period the statistics are on a more uniform basis than in previous years. In this period, the fatal casualties to passengers from train-accidents varied annually between 71 and 367 in a passenger-mileage varying between 25,000,000,000 and 35,000,000,000 miles. In 1914 the record was made of 71 fatal casualties, or a proportion of one to 494,778,436 passenger-miles.

To bring these statistics into some sort of comparison with British statistics, it should be noted that these casualties occurred on a line-mileage increasing from 224,603 miles in 1906 to 252,230 miles in 1914; the British mileage being about stationary at 23,000 miles.[1] In 1914, 315 out of a total of 1112 operating-companies in the United States, had a clear record in this respect. These companies operated a line-mileage of 113,333 miles, which is almost equal to the combined mileage in Austria-Hungary, France,

[1] In the United Kingdom, which boasts of an occasional year without a single fatality to a passenger from a train-accident, the record for the past forty years has averaged 21 a year. Compared on the basis of units of risks, of mileage and traffic in the two countries, this would be equivalent to over 210 a year in the United States. — Railway Statistics of the United States for 1914. Bureau of Railway News and Statistics, p. 117.

Germany and the United Kingdom. The traffic of these companies included 43.5 per cent. of the total passenger-mileage of the country, and 50.9 per cent. of its total ton-mileage. There were 104 managements operating a mileage equal to that of the United Kingdom which, in the four years 1910–1914, had no fatal casualties. There were also 23 managements operating 34,826 miles of line on which but one passenger lost his life in a train-accident in 1914 on each line. There were 338 managements operating 148,159 miles of line, or 58 per cent. of the total mileage of the United States, on which but 23 passengers were killed in train-accidents in 1914. The total number of passengers carried over this mileage in that year was 573,800,000, with a mileage of 20,234,000,000 miles, equivalent to over half a billion journeys of 35 miles each.

The statistics as to non-fatal casualties to passengers in train-accidents cover larger numbers, but among them are included many of minor importance and, to some extent, of questionable origin. Such casualties on British railways numbered 683 in 1912 and 723 in 1913. In the United States, similar casualties amounted to 7515 in 1913 and to 5993 in 1914, which is about equivalent to the numbers reported in the United Kingdom, in proportion to the line-mileage.

There remain to be considered the casualties to passengers from other causes than from train-accidents; such as falling from trains, or in attempting to get on or off a train in motion, or in crossing tracks. From the comparison in the note below, the fatalities to passengers from these causes were far less, proportionately, in the United States.[1] The greater number of non-fatal casualties is in some measure due to the stricter reports required by the Interstate Commerce Commission, yet, even in this matter, the number is less than three times as much with eleven times greater mileage. The result, in general, is remarkable, in view of the greater freedom of movement at stations which is permitted to passengers in this country.

The casualties to employees are to be considered apart from those to passengers. In their hazardous occupation, they are daily and hourly exposed to dangers from which passengers are exempt. This is clearly shown in the accident-statistics given in Appendix VI, Table I. In

[1] Casualties to Passengers Other Than in Train Accidents

	United Kingdom		United States	
	1912	1913	1913	1914
Killed	100	117	195	152
Injured	2,843	2,918	6,892	7,047

Bureau of Railway News and Statistics.

comparing statistics of casualties of this character with others covering previous years, they should be considered in connection with the train-mileage in the periods under comparison,[1] which was as follows:

1907–1909, average	1,171,242,407 miles
1913, average	1,327,749,456 miles
1914, average	1,293,629,513 miles

On this mileage, the casualties to employees per train-mile were as follows:

Killed	Injured
1907–1909, one in 687,520 miles	One in 57,366 miles
1913, one in 861,056 miles	One in 45,141 miles
1914, one in 993,570 miles	One in 52,244 miles

It is remarkable that, while the proportion of train-mileage to one death of an employee in service, in the periods under consideration, should have increased by 44 per cent., the proportion of non-fatal injuries should have remained about stationary. This difference may partially be accounted for by the stricter demands for information in the reports to the Interstate Commerce Commission as to minor injuries, and to the effect of legislation for insuring compensation to injured employees.

The virtually complete equipment of the rolling-stock of the country with automatic couplers has not effected the diminution in coupling-accidents that might have been expected. The casualties from this cause have been as follows:

	Killed	Injured
1907–1909 (average),	202	3,150
1913	195	3,360
1914	171	2,692

As such casualties occur mainly in switching, they may be considered in proportion to the estimated mileage of switching-engines, as follows:

[1] Casualties to Employees. Average for 1907–1909

Causes	Killed	Injured
Coupling cars	202	3,150
Train accidents	559	5,401
Falling or jumping from trains	513	10,081
Struck by trains	359	883
Overhead obstructions	70	902
Total	1,703	20,417

Switching Mileage

Killed	Injured
1907–1909 (average), one in 1,426,286 miles	one in 91,430 miles
1913 (average), one in 1,776,122 miles	one in 103,086 miles
1914 (average), one in 1,996,007 miles	one in 124,883 miles

There is a progressive diminution in coupling-accidents indicated in this comparison, however, while there will always exist an irreducible minimum due to the recklessness that accompanies habitual exposure to danger.

In examining these accident-statistics, attention is drawn to the preponderance of casualties of employees due to falling or jumping from trains or from getting on trains in motion, in proportion to the total number of the casualties to employees.[1]

From these statistics, it appears that about one-third of the deaths and one-half of the other casualties to employees in railway service occur from causes not directly affected by train-accidents but are probably due, to a great extent, to the indifference to danger which has contributed to coupling-accidents. From the proportionately larger number of non-fatal casualties, it may be assumed that they were mainly slight injuries.

The Interstate Commerce Commission's accident-statistics for 1916 exhibit a total of 9366 deaths and 180,380 injuries. This muster-roll of casualties, appalling as a whole, admits of very considerable reductions when considered solely from the standpoint of railway operation. It may be separated into its component parts, as follows:

Casualties To	Killed		Injured	
	No.	Per Cent.	No.	Per Cent.
Passengers	283	.030	8,379	.047
Employees	2,272	.243	43,152	.239
Others, not trespassers . .	1,478	.158	4,444	.025
Trespassers	4,847	.517	5,109	.029
Shop-hands	486	.052	119,296	.660
Total	9,366		180,380	

[1] Casualties to Employees in Falling or Jumping from Trains

	Killed		Injured	
	No.	Per Cent. of Total	No.	Per Cent. of Total
1907–1909	513	30	10,081	49
1913	567	43	15,110	60
1914	640	41	16,565	55

From this analysis, it appears that over half of the persons killed were trespassers, and but 27 per cent. were passengers or train-employees. Of the other casualties, two-thirds were to shop-hands and about 29 per cent. were to passengers and to employees in railroad operation.

In estimating the comparative safety in train-operation, a distinction is to be observed between casualties which result directly from train-accidents, those occurring from other causes, and those not connected with railway operation, as follows:

CASUALTIES ON RAILROAD PROPERTY IN 1916

Persons	Train Accidents		Other Causes		Total	
	Killed	Injured	Killed	Injured	Killed	Injured
Passengers . . .	141	3,850	142	4,529	283	8,379
Employees . . .	313	3,412	1,959	39,740	2,272	43,152
Non-trespassers .	11	92	1,467	4,352	1,478	4,444
Trespassers . . .	84	119	4,763	4,990	4,847	5,109
Total . . .	549	7,473	8,331	53,611	8,880	61,084
Shop hands . . .					486	119,296
All casualties . .					9,366	180,380

The great disparity between these classes of casualties induces a further analysis of those occurring from other causes in railway operation proper than from train-accidents, which may be divided as follows:

Causes	Killed	Injured
Coupling	123	2,194
Overhead obstructions	64	1,323
Falling from trains	441	12,488
Other Causes, classified	628	16,005
Other Causes unclassified	7,703	37,606
Total from Other Causes	8,331	53,611

As to classes of persons, the unclassified casualties were divided as follows:

	Killed	Injured
Passengers	142	4,529
Employees	1,331	23,735
Non-trespassers	1,467	4,352
Trespassers	4,763	4,990
Total	7,703	37,606

A further discussion of official accident-statistics seems to be warranted by the impression that they have made upon public opinion as to the characteristic recklessness attending railroad operation in the United States. Such an impression may well result from a statement, without further comment, that in the year 1916, 9366 deaths and 180,380 lesser casualties occurred in operating the railway system of this country; when, in fact, from train-accidents, there were but 549 deaths and 7473 other casualties, of which only 141 deaths and 3850 other casualties were suffered by passengers.

Our railway managements may well take exception to statistics which include 486 deaths and 119,296 other casualties to shop-hands, or about two-thirds of the total, with those actually occurring in railway operation. This is of special importance in a comparison with railway casualties in European countries, in which the statistics are confined to accidents occurring in train-service, and which do not include casualties due to the sufferer's own fault or mischance. A special committee appointed by the American Railway Association to consider this matter, has requested the Interstate Commerce Commission to adopt a more definite classification of casualties as to causes and persons, with especial reference to persons neither passengers nor employees, and as to a clearer segregation of industrial casualties and of casualties to trespassers. The committee has also suggested that a relative measure of traffic-efficiency in these respects should be indicated by the number of accidents in proportion to the locomotive-mileage and, as to industrial accidents, in proportion to the number of working-hours. The committee has further endeavored to induce the Railroad Commissions in the different states to conform to the requirements of the Interstate Commerce Commission with reference to accident-reports.

If "Safety First" consists in precautions against accidents, in contradistinction to provisions for mitigating their consequences, a discussion of their causes should precede a search for remedies. As affecting railroad operation, an accident is an unforeseen occurrence which interrupts the normal train-movement. Other accidents may be properly separated into two classes or groups — those for which railroad managements may justly be held responsible, as resulting from defects in track or equipment or regulations; and those beyond their control, as when caused by malice, or by negligence, or by disobedience of orders. Against this latter class of accidents, precautions are of no effect. They can only be diminished in number by the intervention of the strong arm of the Law.

Collisions and Derailments

Accidents to trains are not always accompanied by casualties, and their number can not be ascertained from casualty-statistics. They are either collisions or derailments. Collisions are of four kinds: butting-collisions, parting-collisions, "side-swipes" and rear-collisions.

Butting-collisions can only occur on a line, operated under single-track rules, either when those rules are not strictly observed or when they have been superseded by train-orders. A failure to deliver such orders to all trains thereby affected is the most frequent cause of butting-collisions, though they may occur from a misinterpretation of orders. They are but rarely due to errors in the orders themselves, as the authorized forms to govern special train-movements are in such general use that errors of this kind are only likely to occur when the presence of some train within the affected district has been overlooked. Butting-collisions also result from misplaced switches. Switches may not only be left wrong after having been used; in two instances on the same line, a switch was opened in front of an approaching train. Both trains had been somewhat delayed; the man sent to let his train out of the siding sat down near the switch, became drowsy and, when aroused by the noise of the approaching train, half-consciously changed the switch before the train had passed it.

Parting-collisions occur from the separation of a moving train in sections and are caused by deficient draw-gear. They have become less frequent since the introduction of standard couplers, and serious consequences are averted by the quick action of the air-brakes on the rear section of the parted train.

Side-collisions are caused by cars standing on a siding so near the main line as to be struck by a passing train. On lines with two or more tracks, the derailment of part of a train while meeting a train in the opposite direction has occasionally resulted in a side-collision.

Rear collisions have caused most of the catastrophes in train-service. They have occurred, both in Europe and in this country, on lines provided with the most approved methods of operation. In the majority of instances, the original cause has been a delayed train encroaching on the time of a following train, or making an irregular stop between stations.

Unexpected Stops at Unusual Places

The Standard Code of Train Rules, as approved by the American Railway Association, requires that, "When a train stops under circumstances in which it may be overtaken by another train, the flagman must go back immediately with flagman's signals a sufficient distance to insure full protection, placing two torpedoes, and, when necessary, in addition, displaying lighted fusees." "When signal 14 (d) or (e) has been given to the flagman, and safety to the train will permit, he may return. When the conditions require he will leave the torpedoes and a lighted fusee."[1] There are no specific regulations in the Standard Code prescribing the duty of either the conductor or engineman of a train in such an emergency.

[1] Signal 14 (*d*) — four long whistle-blows to return from west or south. (*e*) — five long blows to return from east or north.

Among the whistle-signals, there is a signal of one long and three short blows as an "indication" that the flagman "should protect the rear of train," and there is a rule in the Code that, "Both the conductor and the engineman are responsible for the safety of the train and the observance of the rules, and, under conditions not provided by the rules, must take every precaution for protection."

When a train stops unexpectedly in an unusual place, the engineman has no other specific responsibility placed upon him by the rules, than to give the prescribed whistle-signal as an "indication" that the flagman "should protect rear of train," and there is no responsibility placed upon the conductor other than the general requirement that a conductor and an engineman "are responsible for the safety of the train." That this responsibility is perfunctory in accidents from such rear-collisions, is shown by the fact that it is almost invariably stated that the *flagman* did not, or could not, go back far enough to protect the rear of the train, even on double-track lines operated under a block-system.

Under the Standard Code, upon hearing the whistle-signal, the flagman, upon his own motion, and without waiting for an order from his conductor, is required to leap from the rear of the moving train as soon as he can safely do so, and when he has gone back as far as he thinks that it is necessary, he plants his torpedoes and listens with eager ear for the signal for recall. Unless he has reason for supposing that another train is following closely, he will probably wait for his train to come to an actual stop and will linger for a minute or two, hoping for the recall before he starts to the rear. Often he is required to plunge into the darkness of the night, burdened with lantern, fusees and torpedoes, perhaps facing rain, snow or sleet. It requires a stout heart to hasten toward the glare of an approaching headlight, as he feels his way over slippery cross-ties upon some lofty bridge or long trestle. If, through inadvertence or undue haste, the train moves off before he can return to it, he may pass the night in solitude, perhaps wet, cold and hungry, until some following train stops at his signal and picks him up.

Such are the conditions under which a flagman may be required to protect the rear of a train, when it stops unexpectedly at an unusual place, and it takes pluck and endurance to meet them fully. It also takes intelligent judgment to determine promptly just when a flagman should go back, how far he must go, and what he should do when he gets there. Yet this important duty is intrusted entirely to a novice in training for a conductor's berth, or to some sturdy brakeman accustomed, it is true, not only to the hardships of train-service, but to avoiding them as well. Either through ignorance or doubt, or from fear of being left, the flagman may disappear in the darkness only just around a curve, or near enough to be handy when recalled, and taking the chances as to whether a train is following or not.

This is a fair statement of the conditions under which a flagman is required to protect the rear of a train that is stopped unexpectedly at an unusual place, and of the manner in which he may be expected to fulfill the requirements of the Standard Code. Railroad managements may well be asked whether the Standard Code also fulfills the requirements necessary in such cases; or, if it be admitted that the Code does not fully do so, whether it be not practicable to take some further precaution in such emergencies.

Space Interval, How Best Obtained

Since the necessary interval of space is not practically insured by the block system, as is proved by the frightful catastrophes that have occurred upon lines equipped with its most approved appliances for securing safety in train-operation, it may be well to consider whether some additional means can not be suggested for securing this interval, other than by relying solely upon the intelligence and the devotion of a flagman.

One means may be suggested that does not call for more intelligence or for greater devotion to duty on the flagman's part, but which seeks to obtain both from another source — from the locomotive engineer. He is generally the most experienced man in the train-crew; the best acquainted with the curves, grades, bridges, cuts, embankments and other physical features of the line; the best informed as to the trains passed and to be passed; and, when a stop is made or the train is slowed down at an unusual place, he knows the cause and what the probable detention will be, not only after it has occurred but often before, and can usually select a suitable place to stop. *It is he then, and not the flagman, who should determine when and how the rear of his train should be protected.* If the burden were plainly put upon the engineer to determine, and upon the flagman to act, his action would be controlled by the best-informed man in the crew.

With such a modification of the Standard Code, the space-interval between trains moving in the same direction might be more securely preserved in an emergency, by a more extended recognition of the usefulness of the fusee, which at present is only permissive as a part of the flagman's equipment. How much more valuable in the hands of the engineer! Whenever he is about to stop or to slow down his train at an unusual place, let him be required to drop a lighted five- or ten-minute fusee by the side of the track one mile before the stop is made and the interval between that train and a following one will have been positively secured by a sentinel that will not desert its post, by a signal whose unmistakable light will illumine its surroundings, let the wind blow and the rain fall as they may. It will indeed be a cloud of smoke by day and a pillar of fire by night!

This statement is not hypothetical, but is founded on ample experience. Such a requirement does not do away with the protection afforded by the flagman, but rather increases it. As the rear of the train passes the blazing fusee, the conductor will have warning to see for himself that the flagman goes back. As the flagman crosses a bridge on his way to the rear, he will feel secure against an approaching train when he sees that purple light blazing in the distance. The lighted fusee is as valuable by day as by night, for the smoke from it is so distinctive and even its light, as to be readily recognizable by a following engineer, and its presence is made evident, even around curves. On double-track, the fusee should be dropped outside of the track upon which the train is running, and on divisions of four or more tracks, it can be dropped in the middle of that track by hand, or perhaps more conveniently through a tube.

In the substitution of mechanism for human agency in prevention of railroad accidents, much attention has been given to automatic train-control, and particularly to devices for stopping a moving train independently of the action of the engineman. Such automatic stops are actuated mechanically or electrically in setting the air-brakes. They are useful adjuncts in preventing a train from over-running a block-signal but are not applicable otherwise for the protection of a train making an unexpected stop at an unusual place.[1] A device in use on the New York Subway and on the Hudson and Manhattan tunnel-lines, is connected with the controller and with the brakes, and operates the moment that the motorman releases his hold of the controller, as he can only keep the train in motion by pressing down a button in the top of the controller handle.[2]

Neither automatic blocks nor trip-signals are in use on the New York Elevated lines. It is asserted that their introduction on those lines would require increased headway, and lessen the number of trains by 25 per cent. Out of 3,000,000,000 passengers carried by these lines in the past decade, there have been but three fatal accidents. The few collisions that have occurred have been due to failures on the part of employees.[3]

The requisites of installation for an automatic train-control, as approved by the American Railway Association, are given in Appendix VI, Note II.

Responsibility for Railway Accidents

While railroad managements should not be held morally responsible for train-accidents occurring from causes beyond their control, they should be for such accidents when due to insufficient rules and regulations or to defects in track or equipment. Defects of the latter character are the causes of derailments, and the reports of the Interstate Commerce Com-

[1] The automatic stop or "trip-signal" in use on the New York Subway in connection with the block signals has failed to operate in a case where a collision occurred between two trains approaching a junction.

[2] On July 5, 1911, a motorman on a subway train was killed by his head striking a signal-post. In three car-lengths, the train was brought to a stop with the current cut off and every brake set.

[3] From May 11, 1908, to Dec. 9, 1914, there had been 37 collisions, three passengers and an employee killed and 327 persons injured.

mission furnish appropriate statistics on this subject. In the year ending June 30, 1916, derailments from defective equipment were 4073 and from defective track, 1673. The character of these defects, as classified, is given in Appendix VI, Table III; and also the annual average for ten years which, as summed up, were

From defects of equipment	3,378
From defects of track	1,516
Total	4,894

While no considerable diminution is shown in the number of derailments from these causes, it should be noted that there has been a marked increase in equipment and in train-mileage during this decade. In the same decade, the annual number of casualties from collisions and derailments averaged 12,789, and the average annual damage to road and equipment to $10,356,715.

Automobile traffic has added materially to accidents at railroad crossings, and to casualties from other causes than from train-accidents. For the year ending June 30, 1914, 1147 persons were killed and 2935 were injured at grade-crossings. By far the larger number of such casualties were incurred by a disregard of the injunction to "Stop, Look and Listen" before attempting to cross the line. On the Baltimore & Ohio Railroad, in a record of crossing by vehicles and pedestrians, out of 32,079 instances, in but 298 was this simple injunction observed. More than 18,000 persons took no notice of warning signals, even at crossings where trains were passing at intervals of five to ten minutes. Crossing-gates have not been sufficient for prevention of such accidents. On the Long Island Railroad, in the first eight months of 1915, there were 85 instances of automobiles that had been driven through closed gates. This situation became so serious that the American Railway Association appointed a Special Committee on the Prevention of Accidents at Grade Crossings. This committee has united with a committee from the National Association of Railway Commissioners and the Executive Board of the American Automobile Association in efforts to establish uniformity of warning-signs and signals by State legislation, and for infliction of penalties for the disregard of such warnings. It was further recommended that approach-signs be erected by the highway authorities at a distance not less than three hundred feet from grade-crossings.

Grade-crossing Difficulties. Electric-traction Dangers

The prevention of casualties at grade-crossings has been given prominence in the demand for the elimination of these crossings; notwithstanding the evidence that such casualties occur entirely from disregard of warning-signals and closed gates. A more rational demand is based upon the interruption of highway traffic at such places. This interference increases with the increasing volume of that traffic, and with the greater frequency of passing trains, until it becomes intolerable at street-crossings in large cities. Popular sentiment has been aroused against railroad managements, and mandatory legislation has been sought for the elimination of grade-crossings, without consideration of the conditions and circumstances under which they originated and still exist.

In European countries, where an extensive highway system had preceded the introduction of railway transportation, provision could be made in advance for avoiding level crossings yet, even in England, they exist to this day in greater numbers than is generally thought to be the case. In the United States, railroad construction preceded the existence of highways in extensive areas, and roads were opened indiscriminately at grade, without regard to future exigencies. Under such conditions, it is manifestly unjust that the entire cost of grade-separation should be borne by the railroad company. Where the highway had preceded the railroad, the claim is stronger than where the precedence had been the other way. In either case, it is properly a question of proportionate contribution at the public expense, and this view has generally prevailed where legislative action has been taken.

The expense of grade-separation varies with the topographical conditions, as is shown by experience on the Long Island Railroad. Ten grade-crossings on the Winfield Cut-off were separated at a cost of $1,500,000. In the elimination of 95 street-crossings on Atlantic Avenue, Brooklyn, an expense was incurred of $6,400,000. The elimination of a single crossing in Pittsburgh cost $750,000. The estimated cost of eliminating 203 street crossings in Queens Borough was $12,000,000; the work to be completed in six years. The cost of eliminating all grade-crossings in New Jersey was estimated at $250,000,000, and of eliminating those still remaining on the lines of the Pennsylvania Railroad Company at $600,000,000.

With this information, a conception may be formed of the capital investment required to eliminate all the grade-crossings in the United States. In 1915, there were 255,606 grade-crossings, including 14,913 of one railroad by another. In that year, there were eliminated 61 crossings of railroads and 466 of streets and highways. The unprotected crossings of steam-railroads numbered 40 per cent. of the total of such crossings; of electric railroads, 46 per cent., and of streets and highways, 91 per cent.[1]

Every crossing of steam-railways will sooner or later be the scene of a collision, unless it be protected by interlocked signals. Every crossing of electric railways should be protected either by such signals or by a self-acting gate across one of the lines. Where a public highway crossing is not covered by a watchman, there should be a crossing-alarm. Farm-road crossings should be closed by self-acting gates. In view of the appalling casualties on railroad tracks, such precautions are of far greater importance

[1] For Grade Crossing Statistics, see Appendix VI, Table IV.

to the general welfare than the expensive elimination of 240,693 highway crossings at the rate of 466 per annum.

Some reference may be made to accidents in railroad operation by electric traction. The greater number of injuries to persons and damage to property have been caused by a short circuit of electric current. They occur more frequently, where the third-rail is used as a conductor, from some piece of metal falling across the rails. The concurrent establishment of a short circuit has added to the consequences of collisions and derailments.[1] Apprehension has been expressed as to the effect of the accidental charging of the metallic surfaces of all-steel equipment, though there are no official reports of casualties from this cause. Contact with overhead-wires by train-employees on car-roofs has been a specific cause of fatal injuries. On lines operated in this manner there is less protection from overhead-obstruction, as "telltale" guards can not be used with overhead trolley-wires.[2]

Expedition of Passenger Service

The second factor in importance in Traffic Efficiency is expedition. It is superior expedition that gives value to railway transportation, but this value differs with the purposes for which it is desired by those who avail themselves of it. These persons may be distinguished, as suggested in the discussion of station-accommodations, as commuters and as travelers for longer distances. To the commuter, the railway journeys between his home and his place of business are a part of his daily routine. His every movement is collocated to the minute with the railway time-table. Consequently, even a slight derangement of the train-service on which he depends, causes a serious disturbance in his everyday life. This condition extends to communities within the commuting zone. Their prosperity is affected by the relative frequency of the suburban service, and also by its comparative promptness. This fact is appreciated by the managers of railroads with a heavy suburban traffic, who exert themselves to insure prompt train-service and contribute to the comfort of commuters by specially reserved or "club" cars and, since 1889, by "club trains" on the railways centering in London.

The long-distance travel may be subdivided into that which is confined to journeys within the terminals of a line and that which extends to those terminals or beyond them. The latter class of "through" travelers is ordinarily affected, as to expedition, by competitive conditions. Prompt-

[1] In a rear-collision on the New York Elevated lines, a car caught fire from the third-rail. Two men were killed, and eleven seriously and seven slightly injured.

[2] As to train-accidents, see also, "American Railway Management," pp. 16, 66 and 227; "Restrictive Railway Legislation," p. 126; "Railway Corporations as Public Servants," p. 144; "Problems in Railway Regulations," pp. 279, 305; and as to grade-crossings, p. 274.

ness is not so much a matter of minutes, as in suburban service, but of hours, and it is secured for journeys over connecting lines by continuous-train-service.

The traffic within the terminals of a line is characterized as "local," and local passengers usually receive less consideration as to expedition than either commuters or "through" passengers do. Transportation-officials endeavor to restrict train-mileage by using the through trains for local service at important way-stations. As a consequence, the business and social relations of such communities with each other are often seriously incommoded by derangements in train-service that occur far away from their vicinity.

The minor stations are more fortunate in this respect. Though their train-service may be less frequent, it is not affected by such contingencies, as they are served independently by local trains. On a double-track line, this local service is usually conducted with regularity, but on a single-track line, it is often delayed by the preference given to through trains. These less-favored communities are therefore resorting to the public highways in motor-cars, to an extent which is affecting railroad revenues; and there should, therefore, be provided a more frequent and more punctual service for this class of travelers.

This requirement might be economically fulfilled by a more liberal use of mixed trains between fixed terminals. The trains should be made up of a combination baggage and smoking car and two coaches, attached to six or eight box cars on standard freight-trucks, running on a 25-mile-an-hour schedule. These cars should only be loaded with less-than-car-load lots of merchandise, consigned from one terminal to the other. By this means, the cost of the passenger-service should be sensibly reduced and the loss of business to motor-cars as well; while the frequent and speedy transmission of small lots of merchandise would likewise be of benefit to local-business interests.

Irregularity in train-service has been diminished by the use of more powerful locomotives, by more thorough inspection of equipment and by more careful lubrication of axle-journals, with fewer delays from hot boxes.[1] On single-track lines, passenger-trains are often delayed by congestion of freight-traffic, with consequent loss of time at passing-points, but this should not occur on double-track. There is some statistical information available as to the comparative regularity of train-service. The Public Service Commission of the State of New York reported that, in September, 1916, out of 70,168 trains operated in that State, 76.4 per cent. arrived at destination on time. The average delay for each late train was 24 minutes, and 5.7 minutes for each train run. This statement, however, included suburban-trains to a large extent, with comparatively few and slight delays.

[1] On the New Haven line, there were but eighteen cases of hot boxes on passenger-trains in a week, with a daily car-mileage of 240,000 miles.

46 per cent. of the delays were due to waiting for connections, 3 per cent. to wrecks, 2.7 per cent. to poor track and 2.6 per cent. to locomotive failures.[1]

High Speed in England and the United States

High speed is of less importance than regularity as a measure of traffic efficiency. Continuous high speed is of greater value in long-distance journeys, and is stimulated by competition. The rivalry for the summer-travel between London and the north of Scotland reached a point, in 1895, at which the journey by one route of 523½ miles was made in 518 minutes, and by another of 539¾ miles in 512 minutes; being an average speed respectively of 60.64 miles an hour and of 63.25 miles. The time consumed was abbreviated by long runs without stopping. In 1903, non-stop runs were made of 150, 175 and 185 miles. All previous records were eclipsed by a regular train-service on the Great Western Railway, between London and Plymouth, 245⅝ miles in 233½ minutes without a stop, being at the rate of 63.1 miles per hour.

Competition between rival lines has had a similar effect in the United States. In 1910, the trains between Camden and Atlantic City covered the distance of 55½ miles by the Philadelphia & Reading Railroad in 50 minutes, and by the Pennsylvania Railroad, the distance of 59 miles in 52 minutes, being respective speeds of 66.6 and 68 miles an hour. Such speed in regular service has not been attained on longer journeys. In 1910, the 18-hour schedule between New York and Chicago, over the New York Central route of 979 miles, was at the rate of 54.4 miles an hour. The distance by the Pennsylvania Line is 70 miles shorter, but under less favorable conditions as to intermediate gradients and curvature. The time by both routes has since been lengthened to twenty hours with an additional charge for passage by these trains, which is rebated when a train is over an hour late at destination.[2]

Continuous-train-service at high speed for long distances over a single track was inaugurated with the "New York and Florida Special," between New York and Jacksonville, Fla., on January 9, 1888. The equipment consisted entirely of Pullman vestibuled drawing-room sleepers, a buffet dining-car and an observation car. The train ran tri-weekly, leaving New York at 9.30 A.M., Eastern time, and arriving in Jacksonville at 3.40 P.M. the next day on Central time, or virtually in 29 hours and 10

[1] The "Broadway Limited" train, on the Pennsylvania Lines between New York and Chicago, is scheduled to make the run of 909 miles in 20 hours. During the first six months of 1915, this train was on time on 92 per cent. of the trips.

[2] In June, 1905, the run of 525 miles from Buffalo to Chicago, over the Michigan Central Railroad, was made at the rate of 69.69 miles an hour, excluding stops. In March, 1901, a train on the Plant System between Jacksonville and Savannah, made a run of five miles in 2½ minutes, or at the rate of 120 miles an hour, which is the highest speed on record for a regular train. For comparative speeds of long-distance trains, see Appendix VI, Table V.

minutes. The distance on that run was 1084 miles, and the rate of speed averaged 37.17 miles an hour, with no second track between Washington and Jacksonville, 860 miles. Now, about ten such trains serve the Florida winter-travel from north of the Potomac and the Ohio rivers. The fastest service of this character is rendered between Washington and Jacksonville. By one route, the distance of 755 miles is made, including stops, in 18 hours and 35 minutes, at the rate of 40.8 miles an hour; and by another, 792 miles in 17 hours and 55 minutes, at the rate of 44.2 miles an hour. There are now, however, considerable stretches of double-track on each of these lines.

American Methods. Sleeping-car and Dining-car Service

Convenience and comfort on railway journeys have been greatly furthered since the days when the railway carriage was merely a combination of stage-coach bodies; and nowhere else to such a degree as in the United States. As mentioned in the chapter on Rolling-stock, the American passenger-car was not developed from the stage-coach, but from the long wagon-body in general use in this country. The long passenger-car, with end-platforms and supported on swiveling trucks, has been the fundamental principle in the differentiation of American railway operation from that which originated in England and was adopted in other European countries. It has had a world-wide influence in the subsequent development of methods and appliances for the welfare of the traveling public as well as for economic operation. The car with end-entrances affords facilities for free communication through the train, which was impracticable in the English railway carriage. Acts of violence committed in closed compartments are prevented, the comfort of passengers with regard to the common decencies of life is made possible, and methods of lighting, heating and ventilation can be applied more efficiently.[1]

The European class-distinction in railway operation has not been definitely observed in the United States. The difference in names between the railway carriage and the passenger-car is significant of the difference in social environment. The smoking-car, intended as a relief for passengers to whom smoking is offensive, has virtually become occupied by those who, in other countries, would have been third-class passengers. There is something of the first-class distinction in the occupants of sleepers and parlor-cars, leaving the ordinary thoroughfare cars, or "day coaches," for those who, in European countries, would be considered as second-class passengers. Competition on some of the Western roads has even resulted in furnishing somewhat similar accommodation of a cheaper character in "tourist sleepers" and "reclining-chair cars." The fourth-class accommodations on German roads have no counterpart in this country, where even the immigrant passengers are far better accommodated.

[1] See Chapter IV, pp. 132–139.

The introduction, on British railways, of communication through the train by the use of compartment-carriages with a side-passage way, or "corridor-cars," has exercised an influence toward diminishing class-distinctions by doing away with second-class passenger-fares. As a consequence, the third-class service has been so much improved that it is quite comfortable even for long journeys; as between London and Scotland, where third-class passengers are provided with dining-car service. In democratic Switzerland, the American open car is in general use.

Cars fitted with permanent sleeping-berths, originated in the United States in 1858. Poorly equipped at first, they were developed by George M. Pullman in a car suited also for travel by day, and in a style that was never before attempted.[1] On roads in Continental Europe, the sleeping-cars are corridor-cars, with two berths in a closed compartment and a toilet-room between every two compartments. This arrangement is more objectionable than the open Pullman car, if the occupants of the same compartment are strangers to each other. The standards established by Mr. Pullman in the construction, decoration and furnishings of passenger-train equipment have conduced to the welfare of travelers by rail throughout the world. The Pullman car-service has also benefited them in such matters as convenient lavatories and water-closets.

The identification of train-employees by a distinctive attire had long been customary on European roads before attempts were made to introduce the custom into this country. This innovation, so important to railway travelers, was not generally established until it was made compulsory in the Pullman service. The provision of iced drinking-water with clean glasses, in the Pullman cars, incited the crusade in recent years against the use of drinking-cups in common, and suggested the general introduction of individual cups of water-proof paper, to be used but once and then destroyed.

The presence of an attendant in the sleeping-car afforded the opportunity for serving simple refreshments to its occupants. From this beginning, there has been developed an elaborate dining-car service which has followed sleeping-car service across the Atlantic; as well as luxurious parlor-cars, café-cars and observation-cars, with the auxiliary service of barbers and stenographers. The first sleeping-car with kitchen and pantry, called a "hotel-car," was placed in service in 1867 on the Great Western Railway in Canada. The first regular dining-car, the "Delmonico," was operated on the Chicago & Alton Railroad in 1868.[2]

In Great Britain, light refreshments were served in the Pullman parlor-cars, which were introduced on the Midland Railway in 1875. The first restaurant-car was placed on the Great Northern Railway in 1879. These

[1] Pullman's first car, the "Pioneer," was used on President Lincoln's funeral-train, in April, 1865. "When Railroads Were New," p. 175.

[2] "When Railroads Were New," p. 178.

cars served only first-class passengers, as there was no communication through the trains until the corridor-car trains were put in service on the Great Western Railway in 1892. Restaurant-car service was then extended to second-class passengers, and on the Great Eastern Railway, in 1893, to third-class also; but not on the Great Western Railway until 1903, where, in 1914, there were 88 trains with daily dining-car service. In that year, this service was provided on 457 trains in the British Isles, in the summer-season, and on 403 trains in the winter. Many of these cars are operated on routes of less than two hours in duration, with meals including light breakfasts and afternoon tea.[1]

The American plan of "first come, first served" results in irregular and unsatisfactory service. In a well-filled train, the passage-way to the dining-car may be filled with hungry people, impatiently waiting for seats to be vacated by others who are leisurely finishing their repasts. On European roads, there are two dinners in courses, served one hour apart, and passengers are supplied in advance with tickets for reserved seats at one or the other of these hours. The dining-car service is confessedly unprofitable in itself. It is still more so, if consideration be given to the additional car-mileage and accompanying cost of operation, in comparison with the small percentage of the total number of passengers who are served by it. A steel dining-car, weighing 160,000 pounds and costing perhaps $40,000, with a crew of twelve persons, will seat from 30 to 48 passengers, and not infrequently there are two dining-cars in a train.[2] It is a difficult matter to maintain scrupulous cleanliness in a dining-car that is in regular service and is perhaps dropped at a way-station temporarily, to be taken on by a returning train.

It is questionable whether extensive catering to luxurious habits does not unreasonably affect economic operation. The equipment of café-cars, library-cars and observation-cars is even a more wasteful investment of capital, as they add nothing of substantial benefit to the welfare of the great body of travelers, and are of doubtful value for advertising purposes.[3] There are exceptional cases in which local conditions may warrant such service; as over a route devoted principally to high-class season travel. Facilities for the rest, refreshment and relaxation of travelers on a long railway journey might be afforded by a half-hour stop at a station where all the passengers could obtain meals well served in a comfortable dining-room at moderate prices, including a lunch-counter and basket-lunches.

[1] During 1915, the Southern Pacific Company ran dining-cars nearly 11,000,000 miles and fed 3,207,000 persons.

[2] On the New Haven line, in October, 1914, twelve dining-cars, valued at $400,000, made 175 round trips with a total mileage of 88,700 miles. In that time, 33,440 meals were served, exclusive of 7285 free meals to employees; being an average of 96 passengers per trip. "Passenger Terminals," p. 369.

[3] The "Limited" trains between New York and Chicago are said to average about one hundred passengers per trip. On this basis, the weight of the train, exclusive of the locomotive, is about seventy-five times that of its paying load.

This would also afford an opportunity for a little exercise in the open air while the cars were well aired for a continuance of the journey.

Sanitation

The occasional freshening-up of a closely occupied passenger-car may be associated with a recognition of the germ theory of diseases, and with the attention that should consequently be given to the sanitation of all traveling-conveyances. It is a fundamental principle of that theory that the germs of disease thrive under conditions of combined heat and moisture, that they are merely rendered dormant by severe cold, and that they are only devitalized by complete exposure to dry, hot air. Sweeping and dusting are worse than useless, as they disseminate the seeds of disease instead of exterminating them. This is also true of the use of a blower with compressed air; which is being superseded by the vacuum-exhaust cleaner, in which the dust is collected to be burned. Perfunctory spraying with germicide-solutions has been abandoned in cleaning Pullman cars. The berths are opened up, and bedding and drapery arranged for proper exposure in a temperature of seventy degrees. The cars are then fumigated with formaldehyde in combination with permanganate of potash, heated to a gas in paraffine burners, and the car then kept closed for three hours.[1]

In Germany, the carriages in the trains *de luxe*, which ran to the Russian frontier, were disinfected in a cylindrical compartment of steel tubing, in which a carriage was entirely inclosed. By means of piping along the inner walls, the temperature was raised until the cushions exposed in the carriage had been heated to 110° F. A partial vacuum of about 28 inches was then produced by an electrically-operated air-pump. When more powerful disinfection was required, connection was made with a chamber containing formaldehyde vapor, insuring complete sterilization. The temperature can be raised to 122° F. without injury to the finish of the carriage or to the textile stuffs. The disinfection by heat alone was accomplished within two hours, or in five hours with formaldehyde vapor.[2]

Station Conveniences and Luxuries

Provision for the comfort and convenience of travelers is made at many of the terminal stations in the United States on a scale equally as luxurious as on the limited trains. It is well to provide suitable waiting-rooms and lavatories, properly lighted and warmed, with information-bureaus, carriage-agencies, telegraph and telephone facilities, newstands and uniformed porters but the palatial decorations and trivial accessories of some of these terminal stations border upon extravagance. At the Grand Central Station there is a room for women to have their shoes polished by girls in livery, a "hair-dressing parlor" with walls and ceiling

[1] "Passenger Terminals," p. 250.

[2] Bulletin International Railway Congress, Brussels, November, 1912.

of "Carrara glass," and also a manicure parlor, private dressing-rooms for changing from a traveling-dress to evening costume, with attendants, which can be reserved by telegraph. There are similar provisions for men, and a public barber-shop, that is said to represent an investment of $100,000. The emergency hospital, with a physician in attendance, is more worthy of imitation. There are such accommodations also in the Union Station at Washington, and, in addition, private bathrooms, a Turkish bath, a swimming-pool and several "mortuary chambers."

Ticket Systems

Material changes in the manner of ticketing passengers were brought about with the increasing volume of travel. In early railway practice in England, the familiar methods of stage-coach traffic had been continued in assigning each passenger by name to a definite seat in a carriage, of which there is still a reminder in the use of the term "booking-office" for ticket-office. As there was no communication between the carriages, tickets were collected from the outside running-boards and, as late as 1895, express-trains to London were stopped for this purpose just before entering the terminal station.

In the United States, tickets were at first only issued between principal stations and might be bought or not, at the will of the traveler. Much of the revenue from the passenger traffic was collected by the conductors.[1] For continuous journey over consecutive roads, there were no interline-tickets. Before the consolidation of the line between Albany and Buffalo, a traveler between those cities was required to obtain tickets at Albany, Schenectady, Utica, Syracuse and Rochester; to claim his baggage at the end of each intermediate change of cars, and to provide for his transfer across the town to the other station. Not until 1853 were through-tickets on sale between New York and Chicago, and not until 1875 could a through ticket be purchased from New York to Jacksonville, Fla.

Local tickets were printed on cardboard, with neither number nor date, and were reissued until the ticket-punch was introduced in 1856. Interline-tickets in coupon-form came into general use when the through-fares had been reduced by competition below the total of the intermediate local fares. For the same reason, other forms of tickets were issued, for round-trips, for excursions and for immigrants, also return-tickets, season-tickets, mileage-tickets and half-fare tickets, in such variety that from 500 to 2000 forms are now on sale in the principal ticket-offices.[2] Suburban travel was stimulated by the issue of season-tickets, but for auditing purposes, the issue of commuters' tickets in strips is preferable, as the season-

[1] On the Michigan Central Railroad, the cash-collections on a round-trip between Detroit and Chicago often amounted to $1400, and even to $1800.

[2] Half-fare tickets for clergymen were issued over the Erie Railroad as early as in 1843. "When Railroads Were New," p. 88.

ticket affords no indication of the mileage made with it and, if it is to be shown each time that it is used, it is of no advantage to the habitual commuter. For the convenience of commercial travelers, a special form of ticket was issued on a mileage-basis. This privilege has been extended to include several persons in a party and to cover connecting-lines, until the mileage-traffic now contributes appreciably to passage-receipts.

The exhibition of tickets at the entrances to train-platforms is of benefit to travelers, where there are frequent train-departures at terminal stations, as it insures their direction to the proper trains. The obstruction by turnstiles at these entrances is objectionable to passengers with children and hand-luggage, and is not necessary for the exclusion of loiterers. The admission of persons accompanying passengers to the trains can be regulated by the issue of platform-tickets. These tickets produce a considerable revenue at important stations, and are conveniently distributed from automatic machines adjacent to the platform gates, which were introduced in 1906 on the Metropolitan Railway in London.[1]

Restricting the entrance to platforms to ticket-holders is not as common in the United States as in Europe. Its extension to way-stations in general is unnecessary for travelers, and would require a very considerable increase in the number of station-employees. For this reason, even in Europe, it is not enforced at minor stations and, in Switzerland, only at very busy stations. In Italy, tickets are not taken up on the trains, but are exhibited on entrance to the train-platforms at terminals and to the waiting-rooms at way-stations; and are surrendered on leaving the platforms. But wages are low there, and employment on the railways forms an important part of the political patronage.

Long-distance travelers have been much benefited by the establishment of city ticket-offices in the interest of competing lines. In Europe, this service is more commonly rendered by tourist-agencies, which are indispensable to travelers unfamiliar with foreign languages and customs. The agencies provide tickets for any desired route, with information in several languages with regard to luggage, custom-house inspection and other requirements. The tickets are arranged in consecutive leaflets in book-form, which is preferable to our cumbrous coupon-forms for long journeys. For the establishment of this invaluable service, travelers are largely indebted to the world-wide agencies of Thomas Cook & Son, whose uniformed representatives are at hand at many important railway terminals in Europe, prepared to give assistance to whomsoever may desire it. In this respect, Thomas Cook has rendered a service to travelers similar to that for which we are indebted to George M. Pullman in the matter of car-service. At the principal terminal stations in Germany, seats in the

[1] On the Prussian Railway system, 31,000,000 platform-tickets were issued in 1910; an average of 85,000 per day, yielding a revenue of $735,000. "Passenger Terminals," p. 286.

ordinary carriages could be reserved a day or so in advance, at a slight additional charge. The carriage-seats were numbered and then labeled "reserved." Such concession to persons traveling in a party, might be made in this country, instead of confining it to the Pullman service.

Baggage Handling

Handling and forwarding baggage, like the issue of railroad-tickets, was stimulated in its development by competition between rival lines for the patronage of travelers on continuous journeys for long distances. English railway carriages were originally built with a baggage-compartment between the passenger-compartments, similar to the boot of a stage-coach, into which a porter placed the luggage of a passenger as he took his seat in the same carriage. To those who are accustomed to the American method of checking baggage, it seems remarkable that it should be delivered at destination to whomsoever may claim it without further identification; yet, in London, this course is still pursued on local trains, even at terminal stations. It has its advantages in the speedy delivery of luggage, and with little probability of its being wrongfully claimed.

In American railway operation, some other means of identification became necessary, since train-baggage is carried in a separate car, identification being provided for by means of brass checks in duplicate, bearing serial numbers and the initial letters of the corporate title of the railroad company. Formerly, one of these duplicates was delivered to the passenger and the other attached to the piece of baggage by a leather strap. This plan required the resorting of the duplicates at the end of the route and their return to the issuing station. With increasing volume of travel, this return became so onerous that card-duplicates were substituted, one of which could be slipped into a receptacle on the strap, and were not reissued. The use of card-checks made it unnecessary to keep a large stock of duplicates on hand as, by filling in the destination on a blank space, they were applicable to delivery at any station on any route, and also at any hotel or private residence, through the intervention of local-transfer agencies.

The strap-check is open to the objection that a duplicate may be mismatched or attached to the wrong piece of baggage, either through carelessness or with fraudulent intent. For this reason, when the American system was introduced abroad for continuous interline-journeys, the plan was changed to the so-called "registration" of luggage by the use of a paper label pasted on each piece. These labels are duplicated for identification and are registered on stubs in the books from which they are taken. The same number is repeated on several labels, which may be pasted on a number of pieces belonging to one passenger. The pieces so numbered are placed together on reaching their destination, to expedite delivery. This plan is an improvement on the strap-check, as it prevents the mismatching of duplicates. In view of the number of pieces handled at a busy terminal, it is creditable to the baggage-men that so few pieces go astray.[1]

The free transportation of baggage, which originated in England as a privilege accessory to the stage-coach fare, became also customary in the United States, until the abuse of the privilege brought about a limitation as to weight, beyond which a charge is made proportionate to the excess. In Continental Europe, this privilege is not granted, except, to a lesser extent, in Switzerland. As a consequence, the quantity of hand-luggage is often augmented beyond the capacity of the racks in the carriages, and to the inconvenience of their occupants. With five times the density of passenger-traffic in the United States, the Prussian railways in 1910 carried only 820,000 tons of baggage which, at 150 pounds apiece, is only about four times the annual average at the South Station, Boston.

It has also been found necessary in the United States to limit the dimensions and weight of articles accepted as personal baggage. This limit is fixed at 45 inches in any one dimension, and at 250 pounds as the maximum weight which can be safely handled by one man. Miscellaneous articles, as musical instruments, bicycles and baby-carriages, when associated personally with a passenger, are accepted as baggage, unless by reason of their number or size, they obstruct the regular service. This has become the case with the baggage, properties and scenery of traveling theatrical companies which, like circus-companies, are consequently transported by special trains and at hours suited for making one-night stands.

The storage of undelivered baggage at important stations becomes a serious burden upon the railroad companies, whose responsibility as a common carrier is thereby changed to that of a warehouseman. The extent of this responsibility may be inferred from the floor-space provided in some terminal baggage-rooms. The limit of responsibility as a common

[1] At the Union Station, St. Louis, the annual average is about 1,500,000 pieces. During the World's Fair period, ending June 30, 1904, there were handled nearly 2,400,000 pieces, an average of over 6500 pieces daily. At the Kansas City Union Station, the annual average exceeds 2,000,000 pieces, and 2,500,000 pieces at the South Station, Boston. "Passenger Terminals," Droege.

Loss and Damage to Baggage. United States

Roads in Class I.—1912–1914

Year	Eastern District	Southern District	Western District	United States
1912	$108,781	$56,044	$130,398	$295,223
1913	112,471	68,916	115,335	296,722
1914	124,779	61,993	110,092	296,864
Average	$115,344	$62,318	$118,608	$296,270

carrier is definitely terminated by making a charge for storage at the end of twenty-four hours.

The temporary care of hand-baggage at a passenger-station had been a virtual perquisite of the newsstand, until its value as a source of revenue became so apparent that it was rented as a parcel-room privilege, or retained by the owner of the station. The parcel-room at the South Station, Boston, is open night and day, with eight employees and a rack-capacity for 1680 pieces. The parcel-room also serves as a depository for lost articles which, at the Pennsylvania Railroad Station in New York City, numbered 3630 during the first seven months that it was in operation.[1]

Express and Mail Business

The transportation of light and valuable articles by passenger-trains was first undertaken in the United States by Alvin Adams, who traveled back and forth between Boston and New York as a private messenger, carrying valuables for banking-houses in his hand-baggage. From this unobtrusive beginning, Adams extended his field of action by contracts with transportation-lines until he founded the Adams Express Company, which, with its subsidiaries, monopolizes the express business on important lines from the New England states to the Mississippi River and the Gulf of Mexico. The success of the Adams Express Company led to the organization of similar companies on other trunk-line routes, in several instances by influential stockholders of the railroad companies. Other railroad companies endeavored to carry on the express-business as part of their regular train-service but, in no instance, has this been successful. The necessity for an organization corresponding to the vast extent of territory served, is shown in the control by three companies of the whole express-service in the United States. The business so far exceeds the capacity of the regular passenger-trains that a large part of it is carried on special trains. The express companies have also entered the field of international banking. In 1907, they issued money-orders and travelers'

[1] Area of Baggage-rooms and of Parcel-rooms

Station	City	Baggage-room Sq. Ft.	Parcel-room Sq. Ft.
Union	Detroit		750
Penn. R.R.	New York	50,000	2,780
Union	Washington	41,683	1,020
Union	St. Louis	42,000	1,475
Union	Kansas City	74,648	2,040
South	Boston	27,794	2,100
C. & N. W. R. R.	Chicago	66,650	1,456

"Passenger Terminals," p. 22.

checks to the amount of $168,000,000, which was equal to 30 per cent. of the postal money-order business in that year.

The prosperity of the express companies has been largely due to their making a house-to-house delivery. In England, this had been customary with the carriers on the public highways before the advent of railways. So, when the colliery-railways took over the carriage of miscellaneous goods, they conformed to this custom and entered into a community of interest with the common carriers, which left no field, as in the United States, for express companies. Nor was there the same extensive area for operation over disconnected railroad-lines. Merchandise-trains cover the greater part of Great Britain in a single night, and goods taken from the warehouse of a London merchant in the afternoon are delivered at the shop of his customer in Scotland during the following forenoon. Special provision is made for the carriage of such valuables as are not intrusted to the post.

There was developed a considerable mileage of railways in Great Britain before they began to be utilized for the dispatch of mails. In 1838, the British government introduced a Bill into Parliament to require railway-companies to carry the mails at such hours and at such speed as the Postmaster-General might direct; authorizing the Post Office Department to use its own locomotives and carriages; to carry passengers on its trains and to keep the lines free from interference with their movements; "a fair remuneration" to be paid for the use of the tracks. This measure was withdrawn, however, and contracts for the transportation of the mails were amicably arranged.

In the same year (1838), the United States Post Office Department contracted for railway mail-service between Washington and Philadelphia. The mails were dispatched in locked bags accompanied by a messenger. Afterward, a compartment was assigned to the messenger, or "mail agent," in the baggage-car, which was fitted with pigeon-holes for sorting mails received at way-stations. Separate post-office cars were in use between Boston and Albany in 1852. The rapid express-trains were known as "The Fast Mail" and mail-bags from way-stations were caught from mail-cranes as these trains passed at full speed. With increasing population, the volume of mail assumed such proportions that, on the trunk lines, the locked bags and paper-mail for terminal destinations were transported in storage-cars and eventually by special train-service.[1] The inclusion of a parcel-post in the railway mail-service is causing an increase in the volume of mail which is likely to greatly delay the regular train-service, unless it is taken by special trains.

[1] The first special postal-train in England was placed on the London & North Western Railway in 1885. In 1915, in the Third Postal District of the United States, which includes all the States between the Ohio and the Mississippi River with Iowa and Missouri, a daily average of 2862 tons of mail was carried on 4000 trains. At South Station, Boston, 250 tons of mail are handled daily, and from 225 tons to 300 tons daily at the Union Station, Kansas City.

Variations in Volume of Traffic

Under certain social conditions, passenger-traffic may be conducted with close approximation to economic efficiency; that is, with vehicles loaded to their normal capacity and with train-resistance in economic ratio to tractive power. This is especially the case with excursion-travel, which permits of passenger-train service in its most economic aspect. Commutation-travel is another example of possible economic efficiency, though it has the disadvantage of almost empty train-service in one direction, during the morning hours, and in the other direction in the afternoon. Emigrant-travel affords long hauls for fully loaded trains with minimum requirements as to speed and convenience, but also with empty mileage in one direction. But, as a general proposition, it is more difficult to combine economic with social efficiency in passenger-traffic than in freight-traffic. Empty cars and lightly loaded trains in one direction is the rule rather than the exception, varying even more with seasonal changes than freight-traffic does. In winter, as in summer, there is a rush of travelers seeking a change of climate, like migrating flocks of birds; at the beginning, few in number, but gradually increasing until the maximum volume in one direction has been attained. Then, by degrees, the direction of increasing and diminishing travel becomes reversed. This class of travelers demands facilities for comfort of a very luxurious character. Sleeping-cars, dining-cars, café-cars, observation cars, all electrically lighted, have to be furnished throughout the vicissitudes of the season, and the ratio of dead weight to paying load is greater than in any other class of train-service.

The relative density of both passenger and freight traffic, per mile of line of our railway-system, for the twenty-five years ending in 1914, is graphically illustrated in Appendix VI, Table VI; in which the effect upon that traffic of the financial disturbances in 1893, 1903 and 1907 are plainly visible. It is interesting to compare the relative situation at the beginning and at the end of that period. The relative increase of traffic, as compared with the increase in line-mileage, is indicative of the marvelous prosperity of our country.[1]

[1] Density of Traffic, United States, per Mile of Line

	1889	1914	Inc. Per Cent.
Passenger mileage	75,325	144,278	91.5
Ton mileage	448,069	1,176,923	162.6
Miles operated	157,759	247,397	56.8

Minor Lines (6,695 miles), excluded in 1914.

The importance of adequate provision for the safety, expeditious movement and convenience of travelers as an element of Railway Efficiency and as affecting the general welfare, is made evident in the statistics of passenger-traffic on the railway-system of the United States.[1] Measured by passenger-miles, the volume of traffic nearly trebled from 1890 to 1912, with an increase of 45 per cent. in railroad-mileage. From 1912 to 1914, it increased about 10 per cent. with an increase in railroad-mileage of .027 per cent. The actual number of travelers was less than the number given in these statistics, for there is a duplication of passengers traveling over two or more lines. But, accepting these figures as a basis for the comparative density of traffic, it appears that the annual rate of increase in the number of passengers per mile of line has been as follows:

1890 to 1900	754 per mile
1900 to 1910	5,098 per mile
1910 to 1912	835 per mile (decrease)
1912 to 1914	4,954 per mile

In the period 1910–1912, the railroad-mileage seems to have been extended so rapidly in proportion to the increase in the volume of traffic as to result in a considerable decrease in its density. This decrease occurred only in the Western Traffic District, where the line-mileage increased by 3276 miles from 1911 to 1912, with a decreased traffic that resulted in decreased density of 5257 passengers per mile of line. The apparent decrease of railroad-mileage from 1912 to 1914 is due to the exclusion from the statistics for that period of the operation of minor lines with a mileage of 6695 miles from a total mileage of 256,547 miles. The traffic in the Eastern District constitutes about 61 per cent. of the total on our entire railroad-system; although it contains but one-fourth of the line-mileage. The density of its traffic is two and a half times that in either of the other districts.

[1] PASSENGER TRAFFIC, UNITED STATES

	1890	1900	1910	1912	1914
No. Passengers (millions) . .	492	576	971	1,004	1,053
Passenger-miles (millions) . .	11,847	16,039	32,338	33,132	35,258
Passengers, per mile of line .	75,751	83,295	134,279	132,608	142,516
Railway mileage	165,936	193,345	240,831	249,852	247,397
Passenger train mileage (millions)			549	585	602
Passengers per train-mile . .			58.9	56.5	58.5
Average journey, miles . . .			33.50	33.18	33.61

Mileage of minor lines excluded in 1914.
See also Appendix VI, Tables VI–XI.

The average passenger-train is made up of a mail car, a baggage and express car, three standard passenger-cars and a Pullman car, with a seating capacity for about two hundred passengers. In the five years ending in 1914, the average number of passengers per train-mile has not varied materially from fifty-eight persons. On account of the duplication already mentioned, the actual average has been somewhat less. The average seating-capacity of a train is therefore over three times the average train-load of passengers.

From 1910 to 1914, the length of the average journey, including duplications, has been about 33 miles for the whole system. But, confining the average to roads in Class I (with annual operating-revenues above $1,000,000), the average in 1911 and in 1914 was the same, 34.49 miles; being between 26 and 27 miles in the Eastern District, and between 50 and 52 miles in the Western District. This difference is due to the fact that the great volume of suburban travel is in the former district. Its effect is shown in a comparison of the total traffic in the Eastern District with that on the Long Island Railroad.[1] With 0.67 per cent. of the total line-mileage of roads in Class I in the Eastern District, the Long Island Railroad carried 6.8 per cent. of the total number of passengers. As a consequence, its passenger-mileage per mile of line was nearly six times greater than the general average.

Density of Traffic

From these statistics, it may be inferred that the density of railroad passenger-traffic will hereafter increase but slowly, and will be restricted in the future, as in the past, by the competition of electric roads. In 1908, the electric roads of Massachusetts, urban and interurban, had a mileage of 2233 miles, which was greater than the mileage of its steam-roads. In that year, the electric roads carried about 600,000,000 passengers, or four times as many as the steam-roads carried. They made three times the car-mileage with less than twice as many passenger-cars. Their revenue from passenger-traffic was nearly $30,000,000, or about three-fourths of the steam-roads' passenger-earnings with much longer average haul. The

1914	Long Island Railroad	Class 1. Eastern District
[1] Mileage of line	398	58,667
No. passengers	41,570,612	608,647,324
Passenger-miles	602,787,853	16,348,655,263
Passengers per mile of line	1,512,718	279,975
Passengers per train-mile	110	65
Passengers per car-mile	27	17.3
Cars in train	4.52	5.6
Average journey, miles	14.5	26.86

passenger-traffic of both steam and electric roads is now being affected by the increasing use of motor-cars upon the public highways. In 1916, there were about 3,250,000 automobiles in use in this country, with an average capacity for three passengers at 5000 miles per annum. This potential passenger-mileage of 48,750,000,000 miles per annum may be compared with electric-road mileage, estimated in 1912 at 38,000,000,000 miles, with an average journey of 4 miles; and with steam-road passenger-mileage in 1914 of 35,258,000,000 miles, with an average journey of 33.61 miles.

Statistics of the density of passenger-traffic in 1914 on the railway-system of the United States are given in Appendix VI, Tables VI to XI, and in Appendix VII, Tables XX and XXII. As the passenger-mile and the ton-mile are not recognized as traffic units in European railway-operation, there is no basis on which a useful comparison can be made of the railway traffic in Europe with that in the United States.

Efficiency in Freight Traffic. Loss and Damage

The freight-traffic statistics in this country, from 1890 to 1914, are given in Appendix VI, Tables XII to XIV, and may be summarized as follows:

Freight Traffic, United States

	1890	1900	1910	1912	1914
Tons, millions	636	1.081	1,745	2,058	1,976
Ton-miles, millions	76,207	141,596	255,016	264,080	288,319
Tons, per mile of line	487,245	735,352	1,071,086	1,078,580	1,176,923
Railway mileage	165,936	193,345	240,831	249,852	247,397
Freight-train mileage, millions			635	612	605
Average train-load, tons			401	431	475
Average haul, miles	119	138	146	143	146

Minor lines excluded in 1914, 6,695 miles.

With respect to Traffic Efficiency, the statistical averages of a railway-system so extensive as that of the United States are not so instructive as are those of the several traffic-districts into which that system has been divided in the reports of the Interstate Commerce Commission. An analysis of these statistics shows that the decrease in density of tonnage per mile of line, from 1912 to 1914, was mainly in the Eastern District, partly in the Western District, with a slight increase in the Southern District.

The average haul on roads in Classes I and II has varied but little relatively in the Southern and in the Western Districts, where the hauls are much longer than in the Eastern District. In this latter district, there has been a material reduction in the average haul on each class of roads. This was probably due to the increase in coal-tonnage, with a relatively shorter haul than is the case with the tonnage of raw products.

It is a striking tribute to the general efficiency of the railway managements that, under the prevailing traffic-conditions, the average train-load in Classes I and II should have continuously increased through the four years 1910–1914 from 401 tons to 475 tons, or 18 per cent. In the Eastern District, the increase was from 469 tons to 549 tons; in the Southern District from 365 to 418 tons; and in the Western District, from 352 tons to 419 tons. Yet, in the same period, with an increase of 9.0 per cent. in passenger-mileage, the passenger-train mileage increased 9.7 per cent. This is plainly a sacrifice of economic efficiency to social efficiency.

The statement of tonnage from points of origin, affords an interesting view of the relative magnitude of products and commodities as elements in the railway-traffic of the country. In the period 1912–1914, one-half of this tonnage originated in the Eastern District, one-sixth in the Southern District and one-third in the Western District. Minerals constituted 57 per cent. of the total tonnage, manufactures, 14 per cent. and forest products 10 per cent. Agriculture contributed but 4.8 per cent. of the tonnage in the Eastern District, 8.2 per cent. in the Southern District and 16.5 per cent. in the Western District. The following comparison of the classified tonnage in this period with that in the period 1905–1909, shows how slight has been the relative change between the several classes, since that time:[1]

	1905–09	1912–14
	Per Cent.	Per Cent.
Agriculture	9.0	9.2
Animals	2.5	2.4
Mines	54.0	57.0
Forests	11.5	10.0
Manufactures	14.0	14.0
Merchandise	4.0	3.8
Miscellaneous	5.0	3.6

The fundamental principles of safety, expedition and convenience apply to efficiency in freight-traffic as in passenger-traffic, differing only as they are applied in the transportation of products and commodities as distinguished from human beings. In the conduct of both classes of traffic, the railroad company becomes an insurance underwriter, but to a greater extent with reference to freight than to passengers, as the responsibility of the carrier is somewhat diminished by negligence on the part of the passenger. The carrier, however, assumes a responsibility in caring for human lives which can not be measured by pecuniary considerations. Yet,

[1] For Traffic Statistics in the period 1905–1909, see "Problems in Railway Regulation," Appendix X.

even when a claim for loss or damage to freight has been adjusted, there remains an economic loss which is distributed among the risks assumed in common, with the additional burden of profit to the underwriter. These losses occur from negligence in packing, marking, billing, loading and delivering shipments; from qualities inherent in the commodities shipped; and fraudulent claims are believed to form a considerable item. In fact, the claims arising from these causes far exceed in amount those occasioned by railroad-wrecks.

This economic waste has been increasing to a remarkable extent. The payments for loss and damage, which amounted to $11,000,000 in 1902, had increased to $27,500,000 in 1908, and to $33,500,000 in 1914, which was equal to 1.59 per cent. of the total revenue from freight-traffic in that year. Of this loss, 18 per cent. was for entire packages, and unlocated damages amounted to nearly 20 per cent. Damages amounting to 12.5 per cent. were attributed to rough handling of cars, and 4 per cent. to improper handling and to unsuitable packages, while 10 per cent. was chargeable to defective cars, of which 60 per cent. was incurred in loss and damage to grain, flour and other mill-products.

The result of an investigation, made by the Interstate Commerce Commission, of payments for loss and damage in the first nine months of 1914, is stated in Appendix VI, Table XV. From this statement, it appears that out of $26,000,000 paid in that period, about $11,000,000 was on account of unlocated loss and damage. It is remarkable that it should have been found impracticable to trace the causes of 40 per cent. of the total amount. Errors of employees and rough handling of cars account for another $4,000,000. Over $1,000,000 charged to improper handling and packing was, for the most part, due to carelessness in packing and to unsuitable packages. Robbery and concealed loss and damage accounted for over $2,500,000. Defective equipment (that is, leaky car-roofs and car-floors), cost another $2,500,000, and improper refrigeration and ventilation cost over $750,000. The losses actually incurred in transportation were as follows:

From delays	$1,704,014
From wrecks	1,577,474
From fire	608,753
Total	$3,890,241

Apart from these transportation-items, 85 per cent. of the total amount paid out in that period of nine months, was incurred from causes which may be summed up as general inefficiency in the inspection of car-repairs, in billing and loading, in the switching-service, and in watchfulness over the property intrusted to the care of railroad-employees. It is a virtual confession of impotence or of negligence on the part of operating-officials, which it was time to bring to the attention of railway-managers through the American Railway Association, and they are indebted to a special committee of that body for a lucid exposition of this situation, in which it was stated that, if the working of the operating-departments were perfected, there need be little loss or damage.

One-half of this loss was in the following commodities:

Fruit and vegetables	$2,056,575
Grain	2,050,380
Live-stock	1,789,314
Clothing and dry-goods	1,736,512
Furniture	1,297,145
Groceries	1,160,281
Flour and mill-products	1,149,231
Meats	775,228
Household goods	771,896
Pottery and Crockery	658,138
Total	$13,444,700

Payment for unlocated loss or damage ran through this entire list of commodities, to the extent of about one-third of the total amount. Other causes affected certain classes more especially, as the rough handling of cars in switching, for which losses were paid amounting to $1,500,000; and particularly for live-stock, furniture, fruit and vegetables. Live-stock claims for delays amounted to nearly half of the losses on such shipments. Losses on grain from leaky car-floors amounted to over $1,000,000 and on flour, etc., from leaky car-roofs to $500,000. Improper refrigeration caused a loss of $538,000 on shipments of fruit and vegetables and of $126,000 on meats. Robbery and concealed loss of clothing and dry-goods amounted to $828,000.

Upon such an analysis of the causes of loss and damage, the special committee of the American Railway Association, in April, 1915, based its recommendations for their prevention. These recommendations included a specific inspection-certificate for each car to be loaded with any commodity liable to damage from a leaky car-roof or to loss of bulk grain from a defective floor. Certain improvements were suggested in the methods of interline-billing and in auditing "over and short" reports, as means for prompt detection of irregularities; as also in the loading and billing of shipments in less than car-loads ("L.C.L." freight), and for greater care in packing, marking and loading such shipments; and, further, that closer attention should be paid by inspection-bureaus to such matters. As to defective cars, the committee suggested that claims arising from this cause should be chargeable to the company on whose line such cars had been loaded. For rough handling of cars, the yard-men should be held to a stricter responsibility, and more efficiency should be displayed in the prevention and detection of robbery. The committee mentioned that, in tracing for delayed shipments, the railroad companies annually transmitted about 5,000,000 telegrams and 3,000,000 letters, at an expense of over $1,000,000; much of which could be avoided by stricter observance of its recommendations as to the practice of tracing shipments. Apparently as a result of the efforts of this committee, a comparison of paid claims for 1914 and 1916 on 84 roads operating 134,132 miles of line, showed a reduction from $19,008,709 to $13,806,280, or 27.3 per cent.

Further investigation by this committee developed the fact that a considerable proportion of damage-claims were due to qualities inherent in the commodities themselves. For instance, the corrosion of galvanized-steel sheets had been found to be caused simply by a change of temperature. This matter of damages from qualities inherent in the commodities shipped, has assumed paramount importance in the transportation of explosives. Serious accidents, resulting in loss of life, in addition to the destruction of property, occurred so frequently from this cause that, in April, 1905, this matter was taken under consideration by the American Railway Association. An instance was cited in which a car loaded with powder, in a freight-train standing on a siding, exploded just as a passenger-train was passing. The train was partially destroyed and fifteen persons were killed. Investigation of such occurrences showed great carelessness and even intentional concealment in the packing of explosives, as well as negligence in loading the packages into cars, and in handling the trains to which such cars were attached.

Safe Transportation of Explosives, etc.

A committee of the American Railway Association was appointed to prepare regulations for the safe transportation of explosives, which obtained the valuable assistance of Colonel B. W. Dunn, an experienced officer in the ordnance department of the United States Army. Under his direction, in 1907, a bureau was organized to enforce the regulations recommended by the committee. Courses of lectures were given by officials of this bureau to railroad-employees, manufacturers and shippers who, by this educational process, were stirred to personal interest in the enforcement of these regulations.

This subject was brought to the attention of Congress, which passed an Act, approved May 30, 1908, and amended July 1, 1910, "to promote the safe transportation in interstate commerce of explosives and other dangerous articles, and to provide penalties for its violation." This Act gave authority to the Interstate Commerce Commission, which promptly incorporated the rules of the American Railway Association in a series of regulations made effective October 11, 1908. By virtue of these regulations, "the Bureau for the Safe Transportation of Explosives and other Dangerous Articles, of the American Railway Association" was authorized, through its agents, to inspect even the methods of manufacturing and packing of explosives "so far as it affects safe transportation." These regulations of the American Railway Association as to the transportation of explosives have been adopted by the Board of Railway Commissioners of Canada, and the Canadian railway companies are members of the Association Bureau of Explosives,[1] which also includes 8 express companies, 12 steamship companies, and 71 manufacturers of explosives and other dangerous articles.

It was found impracticable to regulate the transportation of explosives effectually without regulating that of inflammables. The Act was accordingly amended to include "other dangerous articles," and it became necessary to define such articles with precision, to regulate the manner of marking, for identification, the packages and cars containing them, and to prescribe the methods of packing and handling them. They were classified as inflammable liquids, inflammable solids, and acids.

Among the inflammable liquids, the greatest danger to life and property has been incurred in the transportation of benzine and gasoline, and particularly of "casing-head" gasoline — the condensed vapor of natural gas. In any type of package, whether of glass, metal or wood, there will occasionally occur an accidental leakage and, if the temperature within the car is above the "flash-point" of the liquid, the vapor from it will, in combination with the air, constitute an explosive vapor of which the dangerous flash-point has been fixed at 100° F. As a preventive of such leakage, it was required that tank-cars should be tested by cold water to a pressure of 60 pounds per square inch, and stenciled accordingly.

On Sept. 27, 1915, a tank-car, billed as gasoline, exploded on a siding at Ardmore, Oklahoma, causing 41 deaths and 458 cases of personal injury, with a property-loss of over $800,000. The contents proved to have been casing-head gasoline, and the accident was caused by the removal of the dome-cap of the tank while its contents were subjected to internal pressure from vaporization under atmospheric heat. The attention of the consignee had been called to the continual popping of the safety-valves in the tank which, as required by the regulations, should have been sprayed with cold water until the temperature had been reduced.

In 1914, 52 per cent. of the total damage occurring in the transportation of "other dangerous articles" was caused by gasoline, matches, charcoal and nitric acid. "Strike-anywhere" matches caused 93 fires, with loss of $24,886. Fires from spontaneous combustion of ground charcoal, in 392 fires, cost $140,092, from 1910 to 1915. In 1915, besides the Ardmore catastrophe, there were 24 fires from gasoline, causing the death of 12 persons and injuries to 9 others. In 1915, the breaking of a bottle of nitric acid, unlawfully packed in excelsior, caused a fire-loss of $165,000.

A valuable incidental work of inspection, in 1914, was the correction, in 263 cases, of the dangerous location of storage-magazines of explosives. In this useful service, 1596 storage-magazines and 278 factories were inspected and 5366 packages of explosives were condemned as unsafe. This inspection has been extended to the location of storage-tanks and, in con-

[1] "Problems in Railway Regulation," p. 332.

sequence of the Ardmore accident, of sidings for loading and unloading tank-cars with inflammable liquids, and with more rigid regulations concerning casing-head gasoline. A laboratory has been established for analyzing samples of explosives and other dangerous articles.

A further hazard connected with the transportation of articles not considered as dangerous, has been developed in this work. In 1915, in the transportation of fuel-oil, 8 persons were killed and 36 injured, with property loss of $74,854. In consequence of accidents from explosives in passengers' baggage, this practice was prohibited, with an exception in favor of cylinders of compressed gases used in stereopticon outfits, and also of moving-picture films, when properly packed and labeled. Yet, in 1915, a package of films became ignited in an express-car upon a rapidly moving train. The car had no end-doors and the messengers took refuge on the iron side-ladder, where they rode for seven miles before the train was stopped. The car and contents were destroyed with a property-loss of $50,000. In November, 1914, a paper parcel containing such films was taken into a smoking-car and placed on the floor. After the train was in motion, the parcel burst into flames; 38 persons were badly injured and 3 lost their lives. On investigation, it was found that more than 7000 persons were employed in this service in the distribution of moving-picture films. In 1914, in the transportation of over 600,000,000 pounds of explosives, there were 11 accidents, in which no lives were lost, though 5 persons were injured, with property-loss of $14,106. In the same year, in the transportation of other dangerous articles, there were 470 accidents, in which 11 persons were killed and 109 injured, with property-loss of $257,365.

In 1907, there were 79 accidents in the transportation of explosives, in which 52 persons were killed and 80 injured. In the five years ending in 1915, there have been 42 accidents in such transportation, in which 23 persons were injured, but no lives have been lost, while the total property-loss amounted to $46,481. In 1915, the loss was $127.00! During the transportation of immense quantities of war-material, no explosion had occurred until July 30, 1916, when there was a serious fire and explosion at the railroad-pier on Black Tom Island in New York Harbor, caused in the loading of a barge, in which three lives were lost, and which has been traced to incendiarism. The success attained in this matter should be an example to operating officials as to what might be done with respect to loss of life and property in other ways, by the exercise of experience, common sense and tact.[1]

Through and Local Freight Handling

Adequate facilities for reception and loading, and for storage and delivery, are of far more importance than expedition in transit to the great

[1] For statistics as to accidents in the transportation of dangerous articles, see Appendix VI, Table XVI.

volume of traffic in bulk-freight, in minerals and in grain which, in 1914, constituted 58 per cent. of the total tonnage. These commodities move altogether in car-load lots and mostly in train-loads, at rates of speed so slow as to reduce the average speed of freight-trains to about thirteen miles an hour between terminals. They call for ready reception from mines and elevators, as required by commercial demand, but the time in transit is of little consequence compared with continuous movement sufficient to maintain the necessary reserves in the great industrial centers and international markets. In the distribution of commodities manufactured from raw products, expeditious transit is desirable in proportion to their greater intrinsic value per ton, which is provided for by "fast-freight" service. Perishables and live-stock are given even greater acceleration. Shipments in less than car-load lots receive less consideration, though they are charged relatively higher rates.

The stumbling-block in long-distance freight-traffic is the obstruction at intermediate terminals, where trains are broken up and re-arranged for different districts and for divergent routes. To prevent such obstruction, millions have been invested in classification-yards and in cut-offs. Continuous train-movement is impracticable on a single-track line, on which trains must meet or pass at prearranged places and times. On double-track, freight-trains must clear the running-tracks for passenger-trains and, even on four-track lines where the freight and passenger trains move on separate tracks in opposite directions, slow trains must give way for fast trains. The ideal service for heavy freight-tonnage would only be possible on a double-track line devoted solely to that class of traffic, equipped with automatic block-signals and track-tanks, operated by locomotives of adequate tractive power and loaded to full capacity, in a continuous procession at an economic speed between division terminals just far enough apart for coaling and inspection.

Car Interchange and Car Service

Expeditious transportation by rail would be impracticable, but for the interchange of rolling-stock between connecting lines. The original railroad-corporations controlled only short and disconnected lines, and all freight was billed locally. Shipments to points beyond the line were delivered to forwarding agencies that paid the bills and transferred the goods to the receiving-station of the next line, where they were rebilled with accumulated charges. This course was pursued until the extension of lines from rival seaports, into a region common to both, aroused competition. Such rivalry between a route controlled by a single corporation and one composed of several disconnected lines, induced the construction of track-connections between their terminals with an interchange of rolling-stock for business in which they were alike interested. With the rapid extension of rival routes farther into the interior, and stimulated by competition, the increasing volume of interline-traffic absorbed the freight-equipment, without regard to local requirements. In such emergencies, cars were loaded indiscriminately without respect to ownership. Many strayed far away from the proprietary line, perhaps to be discarded when disabled, or to disappear permanently by destruction in wrecks. Corporations controlling a considerable volume of competitive traffic, demanded some equitable adjustment of the use of their cars by their connections. This was accomplished to some extent by the organization of fast-freight lines, with equipment jointly owned by the companies interested in the traffic in which these lines were engaged. This plan did not cover the entire field of competitive business, and agreements were entered into for equalizing the contribution of cars in such traffic by settlement for their use on a car-mileage basis. This required a special organization on each line for the collection and interchange of data between the companies whose cars were so employed. These agreements were open to misinterpretation and rested entirely on the good faith of the contracting parties. A management, upon whose line a considerable volume of business originated which was common to two or more of these rival routes, could afford to treat such agreements with indifference; as it might direct business to one or another of them. Other managements, with but little interest in common, refused to enter into mileage-contracts and used and abused, at their pleasure, the cars that came to their lines in the ordinary interchange of traffic. "Lost-car" agents traversed the country from ocean to ocean, searching for missing cars by their numbers, wherever they could be spotted, in passing trains or on sidings, and with very little assistance from delinquents.

The car-mileage basis for the interchange of cars had proved to be an insufficient remedy for the misuse of them. It recognized only the wear-and-tear of a car while in motion. It did not recompense the owner for the loss of its earning capacity while the car was away from the proprietary line. An attempt was made to devise a more efficient remedy by the addition of a per-diem charge to the car-mileage charge. This "mixed" basis was to be applied by voluntary agreements through local car-service associations. To insure uniformity in the conduct of these associations, the subject was referred to the only organized body of railroad managers, the General Time Convention, which, in 1889, appointed for this purpose a Committee on Car Mileage and Per Diem Rates. In reporting a plan for uniformity, the committee included the application of a demurrage-charge for the unreasonable detention of a loaded car by its consignee.

Efforts to Increase Car Efficiency. Car Detention

In April, 1891, the General Time Convention was transformed into the American Railway Association, with an increased membership of managements and a wider field of action. In October, 1900, a set of Car Service Rules was adopted, in which the car-mileage basis was replaced by a per-diem charge of 20 cents a day, made effective from July 1, 1902. United action for enforcing these rules was found impracticable for lack of a central organization. This was provided in 1903 under a Car Service and Penalty Agreement, which included the appointment of a Committee on Car Efficiency.

The Committee on Car Efficiency represented only the managements that were parties to the Car Service and Penalty Agreement. Although these managements controlled 86 per cent. of the line-mileage and 90 per cent. of the freight-equipment of our entire railway-system, that agreement had been signed by only half of the managements which were members of the American Railway Association. The parties to the agreement themselves responded but incompletely to its requirements. The Committee on Car Efficiency was kept busy in hearing appeals for the remission of charges and penalties. The arguments in support of these appeals were, for the most part, so intensely technical as to be suggestive of the pleas in a chancery court. The managements which were not parties to the agreement, embarrassed its effective operation. The per-diem basis had the effect of placing a definite penalty upon a foreign road for the unnecessary detention of a loaded car, which penalty, by the application of the demurrage-rule, was transferred to its consignee. This misuse of foreign cars had hitherto prevailed at competitive points without much question. Thousands of cars were thus held out of service while brokers were seeking customers for their contents, or to save to consignees the cost of handling and storage by selling directly from the cars.

The Committee on Car Efficiency reported, in February, 1907, a shortage of 137,000 cars but, in consequence of the non-observance of the demurrage-rule, it was unable to improve this situation. In the enforcement of the demurrage-charge, no support was received from railroad commissions or from public opinion. Several State Commissions formulated their own demurrage-rules and one of them, in an official report, boasted that its rules were "more favorable to the *shipper* than those of any other State in the Union."

In the latter part of 1906, complaints had arisen of embarrassment to commerce, and even of suffering in some communities, from long-continued delay in the transit of necessary commodities. The President of the United States was urged to send a special message to Congress, recommending legislation to compel railroad companies to furnish cars within a reasonable time. A bill of this character was introduced, prescribing penalties and authorizing consequential damages. Meanwhile, through the efforts of the Committee on Car Efficiency, the lack of transportation was remedied in the regions whence the most urgent appeals had proceeded. In July, 1907, there was a general surplus of 37,000 cars and, in April, 1908, of 413,000 cars.

A more efficient means for the prevention of the unreasonable detention of cars by consignees was proposed in the American Railway Association, in the recognition of demurrage-charges by the Interstate Commerce Commission, and the collection of such charges through Demurrage Bureaus acting independently of the local railroad agencies. Through the National Association of Railway Commissioners, the Interstate Commerce Commission subsequently secured the coöperation of the State Commissions with a committee appointed by the American Railway Association, and with representatives of commercial organizations, in the formulation of a set of "National Car Demurrage Rules," which was approved by the National Association on November 17, 1909, by the Interstate Commerce Commission on December 18, 1909, and by the American Railway Association on January 27, 1910.[1]

Notwithstanding the formal approval of these demurrage-charges by the lawfully constituted representatives of the public welfare, their application to cars held for storage-purposes met with determined opposition from those who were profiting by this custom. The Interstate Commerce Commission refrained from extending its authorization beyond a recommendation for compliance with them. Consignees regarded with indifference these efforts to remedy the misuse of railroad-equipment. They relied upon the persuasive effect of a diversion of patronage and interposed technical difficulties in counterclaims for delay in placing cars and by pleas of inability to discharge them by reason of inclement weather. As a consequence of these adverse influences, delivering-lines enforced the rules in a half-hearted way, and placated consignees by rebating the demurrage-charges.

Car Shortage

The efforts of the American Railway Association for securing increased efficiency in the use of freight-equipment had proved but partially effective, when the outbreak of the European War created a sudden and unanticipated demand for such equipment in export-traffic. Cars were arriving at the seaports by thousands daily, which were held in waiting for shipping until, by April, 1915, there were 321,000 cars withdrawn from profitable employment. The storage-tracks at the terminals were filled to repletion and the tracks available for switching were encroached upon to such an extent that loaded trains were hauled back to interior yards to make room for the daily train-movements. As a consequence of these conditions, the terminal lines were forced to refuse to accept loaded cars from their connections. These, in turn, took similar action, until the entire freight-traffic of the country was threatened with stagnation. In this emergency, remarkable efficiency was displayed by the railroad managements. Heavy exports to Russia, which were held up by slides in the Panama Canal, were hauled back across the continent to Pacific ports and many cars with weather-proof contents were unloaded on the ground.

[1] See "Problems in Railway Regulation," p. 335.

By November, 1915, the situation had been sensibly improved, and the American Railway Association took into consideration means for preventing its recurrence. Attention was directed to restricting the use of cars for storage by reducing the period of free time and by increasing the demurrage-charge after the first day subsequent to the free period. It was also proposed to abolish unlimited free time upon cars loaded with export grain. The indifference of certain managements in the enforcement of the car-service rules led the Association to give notice in May, 1916, that from June 1, the Commission on Car Service would impose penalties for non-observance of these rules, to be paid to the companies whose equipment had been thus misused. At the Association meeting in May, 1916, further pressure was put upon consignees' holding loaded cars by the adoption of "National Storage Track Rules," imposing a charge for the use of track-room in addition to the demurrage-charges. The Commission on Car Service was further authorized to prepare rules for the issuance and handling of embargoes.

With the return of autumn in 1916, a season of car-shortage recurred which increased in intensity until, by November 1, 1916, it had reached 114,000 cars; though the situation again changed so rapidly that by February 17, 1917, there were 171,000 cars on the idle list. At the meeting of the Association in November, 1916, provision had been made for the appointment of a Conference Committee on Car Efficiency, composed of operating-officials, to be in permanent session at Washington, for coöperation with the Interstate Commerce Commission in the enforcement of the rules and regulations governing car-service. On December 6, 1916, the per-diem charge had been increased, effective May 1, 1917, and, at a special meeting of the Association on February 2, 1917, the hands of the Commission on Car Service were strengthened for a more rigorous enforcement of the rules by the adoption of a "Car Service and Penalty Agreement" over the signatures of responsible officials of all the members of the Association.

This account of the car-service situation, during the most serious congestion of railway traffic which has ever occurred in the United States, exhibits the conditions which restrict the efforts of railroad managements for improved traffic-efficiency. The situation in this respect, during the past ten years, has been graphically depicted in a diagram attached to a publication by the American Railway Association on February 6, 1917, and which is reproduced in Appendix VI, Table XVII. The comparison there presented between periods of "Car Idleness" and of "Car Shortage" shows that during this decade there have been two periods of considerable car-shortage, in 1907 and in 1916, and that the most serious of these shortages reached maxima of 120,000 to 135,000 cars, with four intervening maxima of idle cars, varying between 195,000 and 413,000; the number of cars in service having increased from 1,840,000 on July 1, 1907, to 2,518,855 on July 1, 1916. In considering these statistics, attention should be directed to the number of cars held for movement or unloading. On March 1, 1917, with a reported shortage of 124,973 cars, there were 123,063 cars thus held out of service. The fluctuations between the maximum and the minimum periods of surplusage and shortage have been frequent and extreme, indicating the necessity for remedies which the managements have not been able to supply, nor the railroad commissions to enforce.

Means for Preventing Terminal Congestion. Seaport Rivalry

The exigencies of traffic, periodically experienced in this country, can be obviated only by such remedial measures as will serve the interests of the producers, no less than those of the middlemen. And this view should not be confined to the ebb and flow of currents of tonnage over a few east-and-west trunk lines, but should be extended to the floods of commerce that sweep over our land from ocean to ocean and from the Great Lakes to the Gulf of Mexico, accumulating in volume, like tidal waves, as they approach the ports, and subsiding in intensity as they recede over the broad intervening area. With increasing prosperity, these waves of export-traffic are progressively increasing in volume and in value.[1] Exports doubled in value from 1896 to 1906, and tripled in the following decade. Upon this business, depends the favorable position of our country in that international commerce which has become of vital necessity to our continued prosperity; and freedom of movement is of first importance as a measure of traffic-efficiency. In the export-business, the port of New York is far in the lead. Its proportion has increased in twenty years from 40 per cent. to nearly 51 per cent., and it is in the New York terminals that the congestion of traffic has been most severely felt.

There should be no attempts to relieve this congestion by the refusal of the trunk-lines to receive freight from their connections by the declaration of so-called "Embargoes"; which are as impotent as a measure of traffic-efficiency as they had proved to be as a national policy. They are at best but temporary palliatives. The resort to them is like obstructing a drainage-system in time of freshet, only to overflow the fruitful harvests farther back. The influx and efflux of commerce should be more efficiently

[1] Exports. — United States. (Millions of Dollars)

	1896	1906	1914	1915	1916
United States	882	1,798	2,113	3,554	5,481
New York	354	622	833	1,797	2,790
New York, per cent. .	40.0	34.6	39.4	50.5	50.9

regulated; and the first step for relief would seem to be to open wider the outlets at the ports. This was the experience in the port of London, where the greatest volume of international commerce has heretofore been concentrated. The port of New York is gaining proportionately in that field, and should have the same measures for relief that have been successfully applied in the port of London.

This is not a matter to be left to private enterprise, either of railroad corporations or of individuals. The commerce of the port of London had suffered for centuries from a reliance upon such a policy, until it became recognized that effective remedies could not be applied by the disconnected efforts of conflicting private interests; but that the situation should be dealt with through an organization which adequately represented the general welfare. The results have fully justified the adoption of this policy, and the communities bordering on New York Harbor should profit by this example. They should not rely upon railroad corporations for anything more than transient storage, nor upon warehouse and dock companies for other facilities than may be required for local purposes. These communities should put aside their sectional jealousies, and unite in furthering the interests which they have in common, by an ample provision, under a central organization, for storing export-commodities as they arrive, with reference to ready access by rail and water and of sufficient extent to accommodate commercial interests awaiting favorable opportunities for export and import.[1]

Without such intelligent measures, the port of New York can not maintain its primacy on the North Atlantic coast. The Dominion of Canada is already prepared to challenge it with facilities provided at the public expense in the port of Halifax. New Orleans has, even now, superior port-facilities, which will draw an increasing proportion of the business of the Mississippi Valley with the greater use of the Panama Canal. The harbor of Norfolk is being provided with spacious pier-accommodation and with modern economic appliances. It is quite as well situated as the port of New York, for either European or South American trade, and is far better prepared to furnish abundant and cheap supplies of coal — the controlling element in conducting sea-borne traffic.

Relieved of responsibility for export-storage at their terminals, the railroad managements will be freer to concentrate their efforts in that field of traffic-efficiency which more directly concerns them, in the supply of transportation-facilities by rail whenever and wherever they may be required. Their obligation in this respect is two-fold; to those interests that are entirely dependent on each of them, and to those which they serve in common. The temptation to favor these latter interests should not prevail over their duty to the former. Their obligations with respect to interline-traffic are now discharged through a multitude of individual and

[1] See Appendix VI, Table XX.

disconnected agencies, which exercise directly an influence over the disposition of transportation-facilities that is not efficiently controlled by superior operating-officials. Division-superintendents and freight-agents, local station-agents, yard-masters and even the foremen of switching-crews can and do neutralize the efficient distribution of empty cars by inertness or by intentional disregard of the regulations which they are expected to observe.

Need of Central Authority to Regulate Car Distribution

Apart from such venality as was uncloaked in an official investigation of the distribution of cars in the coal-traffic, there is one aspect of this underhand favoritism that may be considered more creditable to those who exercise it. For it is but human nature to give preference to neighbors rather than to strangers, and, when this tendency is indulged in, in order to retain or to gain competitive traffic, it is much more likely to be leniently dealt with by those higher in authority.

For the reasons here given, it is futile to expect from local agencies a strict compliance with regulations for the distribution of cars in interline-traffic. This duty can only be efficiently performed by a central organization removed from local influences, with entire control over equipment devoted exclusively to interline-traffic. That such a course is necessary for this purpose, is admitted in a statement made by the Commission on Car Service that, in an inspection of the car-records of 107 roads, there were detected over 40,000 violations of the car-service rules in a single month; and that there was convincing proof that, for years, these rules had been generally disregarded whenever it seemed desirable in the interests of individual roads. The responsibility for an improvement of this situation is not widely scattered over the whole of our railway-system. It rests primarily with thirty corporations which, in 1914, controlled 76.4 per cent. of the box-car equipment. They have but to agree upon a plan for it to be put in effect.[1]

Action of Interstate Commerce Commission in Car Service Regulation

In the case of *Missouri & Illinois Coal Company* vs. *Illinois Central Railroad Company*, the Interstate Commerce Commission held that

"1. The temporary confiscation by carriers of the cars of other railroads and the placing of embargoes against cars being sent off the lines of the owners are alike unlawful and the railroads are expected to make such rules for the return of cars as will prevent such abuses.

"2. The railroads of the country are called upon to so unite themselves that they will constitute one national system; they must establish through

[1] See Appendix III, Table V.

routes, keep these routes open and in operation, furnish the necessary facilities for transportation, make reasonable and proper rules of practice as between themselves and the shippers, and as between each other.

"3. An embargo may be justifiable because of the physical inability of the carrier for some reason to deal with traffic which overwhelms it, but an embargo placed against connecting carriers because of their failure promptly to return cars is not consonant with the service which the carriers constituting the through route are required by law to give.

"4. Railroads are required under the Act to serve the through routes which they have established with other carriers without respect to the fact that in rendering such service their equipment may be carried beyond their own lines.

"5. Carriers are required to make reasonable rules and regulations with respect to the exchange, interchange and return of cars used upon through routes, and where they have failed in this respect the Commission is empowered to determine the individual or joint regulation or practice that is just, fair and reasonable."

Any efficient method for providing against the recurrence of a car-famine must be based upon the exclusive control, by a centralized organization, of sufficient rolling-stock for distribution whenever and wherever wanted. To this stock of equipment, each company interested in inter-line-traffic should contribute its quota of standard rolling-stock upon some equitable basis. The Commission on Car Service has accepted this view in a special report on "Principles for Study of Car Service Problems," in which it classified freight equipment as either

"Special Equipment, *e.g.*, open cars, which necessarily involve an empty return movement, or 'Legal Tender' Equipment, *e.g.*, box cars which are or may be loaded at any time at any point in any direction where there is traffic." "To be just to the railroads themselves and to the public generally, this pool" of legal-tender equipment should be regulated, to the end that there shall be secured to every road the use, when it needs them, of its quota of such equipment "or, in the alternative, compensation in money for the difference. Such regulation can be made effective only by abandonment of the right to physical return to the owner of its own cars, and the substitution of the right to possession and use by each line of 'legal-tender' cars in kind equivalent to the cars by it owned and contributed to the pool."

Special Facilities for Transportation of Mine Products, etc.

The prosperity of extensive regions and of populous communities depends largely upon convenient methods and appliances for the transportation of certain commodities. Coal, coke, ores and other products of the mines, in 1914, constituted nearly 57 per cent. of the tonnage of our railway-system. The many millions expended in providing facilities for loading and unloading such commodities are far exceeded in amount by the investment in rolling-stock devoted solely to their transportation. While the total number of freight-cars increased 35 per cent. from 1905 to 1914, the open-top cars increased 42 per cent. in number and 87 per cent. in capacity.[1] The total coal-tonnage in 1914 could have been carried by this equipment in ten trips, and the total product of the mines in sixteen. There is an investment of some $700,000,000 in this equipment, which can be used for no other purpose but must, for the most part, return empty to the mines.

Refrigerator Cars. Cold Storage

Great sums are invested in special equipment for the transportation of particular commodities classed as "perishables," which require protection from the vicissitudes of climate and from the germs of fermentation and putrefaction. The refrigerator-car was first patented in 1868, though experiments had previously been made on the Pennsylvania Railroad for the transportation of dairy-products and fresh meats in box cars with double sides, roofs and floors, insulated with sawdust and cooled by the insertion of a box of ice in the doors of the loaded cars.

Until about 1875, Western cattle were transported to the seaboard to be slaughtered but, with the introduction of refrigerator-cars, this business was gradually transferred to the Western stockyards and the shipment of dressed meats became an important business. The export-trade has been extended across intervening oceans and between the hemispheres by the construction of cold-storage compartments in ocean-going ships.[2] This mode of transportation was greatly furthered by the use of artificial ice, and was adopted by the breweries in connection with the development of summer brewing. The transportation of products fresh from the fisheries became practicable throughout the country, from the waters of the North Atlantic, the Gulf of Mexico and the Pacific coast.

[1] Mineral Products Transported in 1914 — Tons (2000 lb.)

Bituminous coal	307,875,950
Anthracite	76,006,299
Total	383,882,249
Coke	31,345,056
Ores	101,975,316
Stone, sand, etc.	93,982,351
Other minerals	14,890,694
Total	626,075,666

	1905	1914	Increase	Per Cent.
Total no. freight cars	1,727,620	2,325,647	598,027	35
Total no. coal cars	632,171	899,314	267,143	42
Capacity (tons, 2000 lb.)	21,529,310	40,410,665	18,881,355	87

[2] From 1880 to 1900, the number of cattle slaughtered in the United States increased from 8,000,000 to 24,000,000.

In no part of the country has the use of refrigerator-cars been of more general benefit than along the seacoast of the South Atlantic States. This region had suffered severely from the ravages of the Civil War. The plantation-buildings had been burned or were in ruins; the cotton-fields were overgrown with briers and bushes; the rice-field drainage was useless, and the negroes were leading a shiftless life. In fact, large districts were retrograding into barbarism, until an impulse was given to the growth of perishable fruits and vegetables for the Northern markets, beginning in the vicinity of Norfolk and extending southward into the Carolinas. The discovery of fossil phosphates in this very region provided a necessary fertilizing material. Idle lands were reclaimed; habits of industry were encouraged, and a change was effected in the condition of the resident population which was a striking example of the civilizing influences of speedy and reliable means of transportation.

With the extension of railroads into the peninsula of Florida, the facilities for frequent and rapid transportation induced the planting of orange-groves, which became a profitable industry. Here, also, in a land apparently devoid of mineral-resources, valuable deposits were discovered of phosphate of lime.[1] Fruit and vegetable shipments were made through the seaports until the change of gauge on the Southern roads in 1886. In the first attempts at all-rail transportation, crude appliances for ventilation were of no other benefit than to admit air charged with dust, and the results were so unprofitable to shippers from Florida that the all-rail route would have been abandoned but for the opportune appearance of refrigerator-cars, loaded with beer and with dressed meats for the winter-resort hotels. These cars were loaded back with perishables, and refrigerator-cars became the recognized equipment for this traffic. The experience in the transportation of perishables from the South Atlantic coast was repeated on the coast of the Gulf of Mexico and in California. The shipment of bananas from Central America through Mobile and New Orleans was successfully established in the same way, and also the transportation of cantaloupes and of other perishables from the irrigated regions of Colorado. All these thriving agricultural industries have been made possible by the use of refrigerator-cars, which now number about 180,000.[2]

[1] In 1914, Florida marketed 2,543,876 tons of phosphate rock, being 82 per cent. of the entire production of the United States.

[2] CITRUS FRUIT FROM CALIFORNIA. 1896–1897 — 7,350 car-loads
1897–1898 — 15,400 car-loads, 22 per cent. under refrigeration
1904–1905 — 31,422 car-loads, 51 per cent. under refrigeration
CITRUS FRUIT FROM FLORIDA. 1914 — 26,435 car-loads
PEACHES FROM GEORGIA. 1895 — 743 car-loads
1896 — 2,500 car-loads
1904 — 4,800 car-loads
STRAWBERRIES FROM SOUTHERN COAST. 1897 — 425 car-loads
1906 — 2,613 car-loads
EARLY VEGETABLES FROM SOUTHERN COAST. 1907 — 467,169 tons

In 1885, cantaloupes were grown for market at Rocky Ford, Colorado, and the first car-load shipments were made in 1894. In 1897, the refrigerator-shipments amounted to 121 car-loads and, in 1904, to 1182 car-loads. In 1897, the total shipments from all points were 400 car-loads and, in 1904, 6920 car-loads; the season for car-load shipments having been extended from two months to six months. This remarkable development of production has been due to cold-storage in connection with refrigerator-transportation. Even apples and cabbages are more profitably marketed, when transported, without ice, in refrigerator-cars between November and April to prevent them from freezing, and then, under ice up to September, as a protection from overheating.

The traffic in bananas originated in 1872, in shipments by sail from the West Indies to Boston, which led to the organization of the United Fruit Company. In 1903, this company imported from Central America, 30,000,000 bunches of bananas, averaging 100 bananas each, distributed largely through Mobile and New Orleans. At these ports, extensive wharf-facilities are provided in connection with speedy train-schedules, convenient re-icing stations and immediate delivery into cold-storage. Among other tropical fruits moved in refrigerator-cars, the pineapple is the most important. The importation of this fruit increased from 1366 car-loads of 341,657 crates in 1900 to 3840 car-loads of 960,000 crates in 1908. Meanwhile, the development in the production of this fruit on the line of the Florida East Coast Railway increased from 5000 crates in 1883 to 690,000 crates in 1908.

Refrigerator Transportation for Dairy and Perishable Products

Refrigerator transportation has also been extended to shipments from poultry-farms and dairy-farms which, in one section of a Southern State, were in gross as follows:

	1893	1905
	Tons	Tons
Butter	64,130	127,024
Cheese	9,040	7,421
Eggs	32,097	91,167
Dressed poultry	16,251	41,456

Cars in which milk is transported in iced containers, are operated in trains on a schedule speed of 25 miles an hour to New York City from points 400 miles distant; leaving at 8.00 A.M. and arriving at midnight for next morning's delivery. This business originated on the Erie Railroad in 1875, for a distance of 87 miles from Jersey City. In 1886, the total shipments were about 5,500,000 cans of 40 quarts each. By 1907, they had increased to 15,000,000 cans; an increase, per capita of population supplied, from 96 quarts in 1886 to 136 quarts in 1907.

Efficiency in the transportation of perishables is sought by rendering dormant the germs of vegetable-fermentation and of animal-putrefaction in the commodities transported, by reducing the maximum temperature within the car below 50°. This purpose is accomplished by insulation. The car is built with double walls lined with felt or other non-conducting material; thus forming an inclosed air-space which excludes the external temperature. But refrigeration has also to reckon with the moisture inherent in the commodities themselves, which, condensing on their surfaces, becomes vaporized, causing the germs of decay to become revitalized on re-exposure. This moisture has to be removed by ventilation obtained through screened openings by the motion of the train. The reduced temperature is maintained by the passage of the indraught of air over the ice-bunkers at the forward end of the car and out at the rear through graduated openings controlled by attendants. Under such ventilation, refrigerator service is efficiently rendered from the Pacific coast, across the Rocky Mountains and the arid Western plains, to the humid regions of the Atlantic coast. A device is in operation for removing accumulated gases and heated air from the top of the car, permitting cool air to flow in through the ventilators. In a car-load of peaches from Colorado to New York, the greatest variation of temperature between the floor and the roof was nine degrees.

Pre-cooling and Heating Arrangements

A further improvement in refrigerator transportation has been derived from pre-cooling in cold-storage and the intermediate protection of the commodity from a higher temperature during its transit and redelivery into cold-storage terminals. The pre-cooling of perishables has secured a reliable extension of marketable territory with saving of ice in transit, with greater loading-space and less necessity for high speed.[1] A car-load of pre-cooled fruit, loaded in California at a temperature of 42° and re-iced before starting, received no further refrigeration, and, after a journey of 3255 miles in ten days, arrived at Jersey City with 700 pounds of ice in the bunkers; having been for seven days consecutively in an external temperature between 70° and 90°. A car-load in the same train, loaded at a temperature of 63°, was reduced to 50° on the fourth day out and arrived with a temperature of 48°, having been re-iced seven times during the trip

[1] In a pre-cooling plant of the Southern Pacific Company, at Roseville, Cal., air from the storage plant at 32° is blown through an insulated tube into the ice-bunkers at one end of the car and is exhausted at the other end with the moisture and gases from the fruit. It takes from 30 to 50 hours to cool the fruit to 40° in the center of the car. In the pre-cooling plant of this company at Colton, Cal., there are connections for forty cars.

with from one to two tons of ice at each station. Bananas are pre-cooled with air carried over ammonia-piping to the train-shed in insulated tubes, and there injected through canvas ducts into as many as fifty cars at a time, until the temperature is reduced to 68°.[1]

The effect upon the prosperity of an agricultural region of providing protection from atmospheric conditions in the transportation of perishables has been signally exemplified in the northeastern section of Maine, where the Bangor & Aroostook Railroad was constructed, about twenty-five years ago, for two hundred miles into an undeveloped timber-region. The shipment of potatoes from the line of that road increased from 1,500,000 bushels in 1894 to 12,300,000 bushels in 1906. The special facilities here provided consisted of heating arrangements, as the average winter temperature ranged between 15° and 20° below zero. The "heater" cars are built with hollow walls. Underneath the car-floor there is an oil-stove, from which the heated air ascends through a duct into the space between the walls of the car. Fires lighted at the point of shipment require no further attention for distances of 800 to 900 miles, although an attendant accompanies each lot of five cars. These cars may be used for return-freight, as there are no interior obstructions.[2]

Transportation of Petroleum, etc.

A similar use of special equipment has accompanied the vast development of the petroleum industries. The average daily production of the Oil Creek district in Pennsylvania, in 1861, was 700 barrels. There was no other oil-region of importance until the discovery of oil, in 1885–1886, in the Lima field of Ohio. In 1889, oil was discovered in West Virginia, and subsequently in other states, particularly in California. In 1901, the oil-region of Texas came into notice and produced 30,000,000 barrels in four years. In 1904, oil was discovered in Indiana and in Louisiana, in 1905, in Kansas, and in 1906 Illinois produced 24,000,000 barrels.

The early refineries were situated on the railroad-lines in the oil-districts. The crude oil was piped to them from the wells, and the refined product was shipped in barrels. With improvements in pipe-line transportation, the oil was piped to refineries established within the regions of consumption. In 1899, the Standard Oil Company of New Jersey alone operated 35,000 miles of pipe-lines, representing an investment of $50,000,000. The total production of crude oil was —

in 1874	10,000,000 bbl.
in 1903	100,000,000 bbl.
in 1915	218,000,000 bbl.
in 1916	292,000,000 bbl.

[1] "Freight Terminals," Droege, p. 375.

[2] Most of the information as to refrigerator transportation has been obtained from the Proceedings of the International Railway Congress at Berne, in 1910. Report on "Perishable Goods," by J. M. Culp, Vice-President, Southern Railway Company.

The production of gasoline has been so stimulated by its use as a source of motive power that, in 1915, it amounted to 1,000,000,000 gallons, and the output in 1916 is estimated at 1,500,000,000 gallons.[1] The present consumption of crude oil by the refineries in the United States is estimated at about 1,000,000 barrels daily. The distribution of the refined products is dependent upon the special equipment of tank-cars, which are also used for the transportation of other liquids in bulk. In 1911, the total shipments of this character amounted to about 8,500,000 tons and, in 1914, to 11,600,000 tons; an increase of 37 per cent. in four years. The private tank-car lines alone, in 1917, had a capacity of 4,000,000 tons.

Special Freight Equipment. Private Car-lines

The specialization of both passenger and freight equipment for a particular service has been characteristic of railway operation in the United States. It has, for the most part, originated in the organization of private car-lines in the development of new business-enterprises on a large scale and is, in some respects, a reversion to the original system of separating the ownership of the cars from that of the track. The extent and variety of special freight equipment in organized private car-lines as compared with that owned by railroad companies is as follows:

Special Freight Equipment in Use in the United States

Compiled from Official Railway Equipment Register. March, 1917

Character	1917 Private Car-lines	1914 Railroad Companies
Refrigerator cars	85,895	
Refrigerator cars, fast freight lines	43,591	
Total	129,486	48,886
Tank cars	83,945	8,530
Stock cars	36,825	82,971
Open-top cars	13,852	899,314

Railway Delivery Service in England

In the exercise of traffic-efficiency, the service of a railroad-corporation is, under certain conditions, beneficially extended beyond its rail-terminals. Service of this kind has been co-existent in England with the earliest application of railway-transportation to the carriage of merchandise. As attention was directed to this traffic, it was necessary to compete with the carriers on the public highways by house-to-house service, which included cartage to and from the railway-terminals. Commercial intercourse between the centers of production and consumption was thereby greatly

[1] "The Age of Oil," by Charles A. Stoneham.

facilitated, and to the advantage of dealers trading on a small capital. The necessity for carrying a large stock of goods was sensibly diminished as an order for merchandise received on one day could be delivered early the next morning anywhere in Great Britain. At the London terminals, such freight is received up to 6.00 P.M., and is loaded and dispatched before midnight. From each of the principal stations, there are usually about thirty of these trains every night, of thirty car-loads each, operated at a speed of forty miles an hour. As the cars are of small capacity, full car-loads may be distributed along either the main line or branches without breaking bulk. Overnight delivery is made to Edinburgh and Glasgow, 400 miles away, and, at a later hour, to ports on the East coast of Ireland.[1] The traffic in fresh fish from the seaports is conducted in the same way. The transshipment of household goods from house to house is accomplished by transferring the body of a loaded van from its running-gear to an open wagon, and again, on arrival at the railway, transferring it back to other running-gear.

The cartage of all goods is included in the railway-service, with the exception of bulk-freight. On five railways, there are 18,000 horses in this service; the London & North Western Railway Company alone employs 6000 men and horses. Much of the service of this character is performed in the United States by the express companies, where it has been apparently found impracticable to conduct it as satisfactorily by the railroad companies, because of the far greater area of territory to be covered, the greater capacity of the freight-cars and the more numerous centers of production and distribution. Still, unless railroad-managements with terminals in large cities, adopt some plan for overnight delivery of merchandise, motor-trucks will compete for such traffic, as motor-cars are competing for local passenger-traffic.

The insular position of the British railways induced the extension of their service across the Irish Sea to Ireland, and across the British Channel and the North Sea to the Continent. The development of this service has been stimulated by competition from the several seaport-terminals. In 1912, 167 steamers were so employed by fourteen railway companies. The Lancashire & Yorkshire Railway Company owned a fleet of 33 ships, of which 24 were in the North Sea trade to Continental ports.

Water and Rail Combination Service. Car-floats and Car Ferries

The combination of water- and rail-transportation in the United States, originated in the necessity for maintaining communication across estuaries too broad to be bridged, as exemplified at New York City. Here, the situation of the metropolis between the Hudson and East rivers, induced the establishment of steam-ferries in the interest of the railroad companies,

[1] "Freight Terminals," Droege, p. 307.

with terminals on the farther shores, in order to compete with lines whose terminals were within the city. This competition was not confined to passenger-traffic. The local freight-traffic was of equal importance to the railroads, and to place themselves on an equality in this respect, cars were transported upon floats, which were towed to freight-stations on the city piers. Car-floats carrying from eight to twenty-four cars virtually extended the railroads along the entire shore-line of New York Harbor.[1] In connection with lighterage and grain-elevators, the whole field of domestic and foreign commerce, by river, sound and sea, has been brought into direct connection with the railroads terminating on the west shore of the Hudson River. The water-front of Hoboken and of Jersey City is an almost continuous railroad-terminal, with ferry-slips and piers of an assessed valuation of $93,000,000. The railroad-lines terminating on Manhattan Island have had also to gain access to the water-side, to meet this extension of railroad-service, by the establishment of a similar system of lighterage and car-floats. The results of these measures of traffic-efficiency are to be seen in the commanding position which the port of New York holds in the domestic and foreign commerce of our country.

There has been a similar extension of railroad-service by supplementary water-transportation in the harbors of Boston, Baltimore and Norfolk, under systematic provisions as to efficiency that have not been practicable in the port of New York, by reason of antecedent control of wharf-privileges in special interests. At these ports, and elsewhere, wherever the rails reach the water-front, the extent of the water-borne commerce has depended upon the efforts of the railroad-managements for its development, as has been amply illustrated in the growth of commerce on the Great Lakes. In July, 1909, enough Lake freight passed Detroit to fill 300,000 cars, equal to a daily movement of 200 trains of 50 cars each. For the most part, this tonnage was brought by rail to the ports, and had to be moved again by rail, either as raw material or as manufactured products.

The car-float, itself an American contrivance, has had a further development which is also peculiar to this country, in the steam car-ferry, as an intermediate link in an otherwise all-rail line. In 1875, 173,708 cars

[1] The New York Harbor line has an extent of about 448 miles with about 604 miles of dock and wharf-frontage, of which 44 miles of harbor-line and 93 miles of wharf-frontage are along the shores of Manhattan Island. There are, in addition, 30 miles of harbor-line and 96 miles of wharf-frontage on the New Jersey shore between Amboy and Fort Lee, to which railroad-freight is distributed by lighters. About 1000 cars are distributed daily on floats to stations between Canal Street, on the North River, and Jackson Street, on the East River. The railroads bring annually about 13,000,000 tons of freight into New York City. The Pennsylvania Railroad operates 60 floats and 8 tugs, with capacity of 700 cars, and transfers about 1000 cars daily. The New York Central Railroad operates 41 floats and 20 tugs, with 485 cars' capacity, and transfers about 760 cars daily. The New York, New Haven & Hartford Railroad operates 46 floats, 19 tugs and 2 steamers, with 771 cars' capacity, and transfers about 2000 cars daily, for distances of six to thirteen miles. "Freight Terminals," Droege.

were transferred across Detroit River. In 1909, 735,753 cars were there transferred by nine car-ferry boats, the largest being 351 feet long and carrying 24 freight cars, and the longest distance between terminals being about five miles. From three to eight hours were consumed in crossing the river and in passing through the terminal yards.[1] Since the construction of the Detroit River Tunnel, the most important ferries of this character are in operation between San Francisco and the railroad terminals on the opposite shore of the bay. Between Vancouver and Vancouver Island, British Columbia, the car-ferry accommodates twenty-five passenger-cars. Car-ferries are in operation at several points on the Great Lakes.[2]

This plan for the continuance of railway-service across rivers, estuaries and lakes, was applied, in 1915, in connection with the Florida East Coast Railway, which is built for over 100 miles along the Florida Keys and the intervening channels and sounds to Key West. Connection is there maintained with the Cuban railway system at Havana by car-ferries. These vessels, two in number, are each of 3500 tons, 357 feet long and 58 feet beam, with speed of 14 miles an hour and capacity of 30 freight-cars. The steamers are oil-burners and consume the equivalent of 32 tons of coal on the round trip of 184 miles between Key West and Havana. The success that has attended the establishment of car-ferry service across the Florida Channel seems to warrant the adoption of similar "all-rail" transit across the English Channel, where the voyages are shorter and under no more disadvantageous conditions.

Railway Control of Ocean Steamer Service

The control of steamboat and steamship service in the interest of railroad corporations, is to be desired, where such control is of benefit to the public, as a measure of traffic-efficiency; as where it involves the traffic interchanged between otherwise disconnected railway-systems on the Great Lakes, and on the bays and sounds along our seacoasts. An undivided responsibility, in connection with continuous service by land and water, is of prime importance in the transportation of passengers and of general merchandise. Such service is conducted more efficiently, as to safety, dispatch and convenience, where the water-line is an adjunct to a great railway-system than where it is the sole source of profit to its owners. This is not so much the case with water-borne commerce in bulk-freight, which is received and distributed under different port-conditions. The well-equipped steamers on Long Island Sound, Chesapeake Bay and the Great Lakes furnish a high-class service that is unequaled elsewhere.

Our coastwise commerce is also conducted more satisfactorily in con-

[1] "The Detroit River Tunnel," W. S. Kinnear, Trans. Am. Soc. C. E., December, 1911.

[2] See Appendix VI, Table XIX.

nection with the railroad-lines, by which the service is continued into the interior, than if it were managed in separate and conflicting interests; and the business of the terminal ports is benefited by a more frequent, regular and efficient service. To some extent, this statement may be applied to the conduct of commerce across the oceans. A great port, like New York, furnishes profitable business for independent steamship-lines in the carriage of passengers and general merchandise; but ports of less local importance can not furnish the basis for an equally high-class service, unless it be provided in the interests of the railroad-lines terminating at such ports. The Pacific coast has been largely indebted to such interests for the maintenance of their commercial relations with the farther shores of the Pacific Ocean. The political relations of our country with those regions, have also been facilitated by the existence of these steamship-lines under our national flag. It requires no lengthened forecast to conceive of an enormous expansion both of our commercial and of our political relations with the other countries bordering on the Pacific Ocean. If our transcontinental systems are to be debarred from contributing to the maintenance of these relations, not only their interests, but the welfare of our country also, will be handicapped in the rivalry of the ports on the coast of British Columbia, which will have the backing of the Canadian railway-system, with an unbroken control of steamship and railway service from the shores of the British Isles, across the Atlantic Ocean and the North American Continent to thousands of miles of the seacoasts of Asia, Australia and New Zealand.

This review of the subject-matter of railway-transportation in the United States, covers an area of territory about equal to that of the continent of Europe, and a mileage greater by 11 per cent. than that of the entire railway-system of that continent, but with only one-fourth of its population. Railway-service in the United States is at present rendered to its population at the rate of about one mile of line to every 389 persons, while that rendered to the population of Europe is at the rate of about one mile to 1900 persons.[1] This statement affords some conception of the increase in trackage, equipment and terminal facilities which must be provided in advance for the requirements of our growing population, and also of the amount of capital that should be invested for this purpose.

	United States	Europe
[1] Area, square miles	3,026,789	3,872,561
Railway mileage	261,554	234,625
Population	101,882,479	464,681,000

CHAPTER VII

TRANSPORTATION

Relation of Transportation to Other Railway Departments

The purposes of Transportation are accomplished by means of Motive Power, Rolling-stock and Roadway; its subject-matter is Traffic. The efficiency of the Motive Power Department is shown in the furnishing of tractive power and in the maintenance of a plant for the same. The efficiency of the Rolling-stock Department lies in the design and construction of vehicles suited to the traffic in which they are to be engaged, and in diminishing the effects of external and internal shocks and friction upon such vehicles while they are in motion. The efficiency of the Roadway Department is manifested in the location of a railway line, in conformity with its physical and social environment, to the greatest advantage and at the lowest possible cost; in the construction of works to facilitate communication across and beneath rivers and mountain-ranges; in reducing gravity's resistance to train-motion on an ascending-grade; in lessening external friction on curves; in diminishing, through careful maintenance, the effects of oscillation and impact between trains and tracks; and in providing adequate means for the protection of train-movements and for the receipt and delivery of persons and commodities. However skillfully these several instrumentalities of railway transportation may have been designed, constructed and maintained, it is the intelligent coördination of them by the Transportation Department that secures their profitable application to the movement of traffic with safety, dispatch and convenience.

Fundamental Principles

The primary office of the Transportation Department is the economical application of traction to train-service, or of Energy to Matter in Motion. Hence the physical laws which control this relation should be clearly understood by those who have to do with railway train-service.[1] The

[1] As expounded by Sir Isaac Newton, in 1685–1686, these laws are

I. — Every body continues in its state of rest, or of uniform motion in a straight line, except so far as it may be compelled by force to change that state.

II. — Change of motion is in proportion to the force applied and takes place in the direction of the straight line in which the force acts.

III. — To every action there is always an equal and contrary reaction; or, the mutual actions of any two bodies are always equal and oppositely directed. — Century Dictionary.

distinctive characteristic of matter is inertia.[1] Matter can neither start itself nor stop itself. It can only be set in motion by external impetus; its motion can only be arrested by external resistance. Matter can only be set in motion by power derived from vital energy or from inorganic force. Once in motion, its onward course can only be arrested or modified by resistance originating in one of these forces and appearing either as gravity or as friction, except as due to collision.

These propositions are as applicable to railway-transportation as to other aspects of matter in motion. The energy derived from heat is converted, through the mechanism of the locomotive, into power by which the train is set in motion. Once the train is in motion, that power is spent in overcoming the resistance offered to the continuance of that motion by the effect of gravity on ascending grades, by the internal friction between the moving parts of the train, by the external friction of its wheels against the rails, and by the frictional resistance of the atmosphere. The inherent inertia of the train has first to be overcome, either by the action of gravity or of tractive power. The energy required to set a train in motion is, so to speak, stored up in the train before it begins to move; and the amount of that energy, as a quantitative force, is proportionate to the mass of matter in the train. But, as soon as the inertia of the train has been overcome, then the stored-up energy is released and reappears as work in maintaining the train in motion, or as velocity.[2]

Theoretically, once a body is set in motion, it continues to move on indefinitely with an initial velocity proportioned to the energy exerted in overcoming its inertia. That is, if a train were to be started by a push from a locomotive, not coupled to it, that train would continue to move on indefinitely at the same velocity, upon a track which was uniformly level, straight and smooth, provided that it encountered no resistance. But even upon such a track, its velocity would be retarded by the resistance offered by the friction of the atmosphere and by the journal-friction of the car-axles. These retarding effects would gradually absorb the energy of motion and bring the train to a state of rest again. Therefore, it is necessary for a continuance of uniform motion that there should be a continual expenditure of energy by the locomotive in the form of tractive power.

Practically, no railroad-track is level for any considerable distance. Its physical environment compels a change of direction vertically, and here there comes into action an energy of a different kind from that de-

[1] Inertia. — That property of matter by virtue of which it retains its state of rest or of uniform rectilinear motion, so long as no foreign cause changes that state. Quantitatively, inertia is the same as mass. — Century Dictionary.

[2] Velocity is the rate of motion. The velocity of a body is *uniform*, when it passes through equal spaces in equal times. It is *variable*, when the spaces passed through in equal times are unequal. It is *accelerated*, when it passes constantly through a greater space in equal successive portions of time. It is *retarded*, when a less space is passed through in each equal successive portion of time. — Century Dictionary.

rived through the expansive property of steam, as developed in the tractive power of the locomotive. This is the Energy of Position or Potential Energy, as distinguished from the Energy of Motion or Kinetic Energy, and is due to that mysterious law of physics, which holds the universe together, the Attraction of Gravitation, the effect of which was accurately ascertained by the experiments of Galileo in 1589–1591.[1]

In accordance with the Third Law of Motion, if the momentum acquired by a falling body in a vacuum could be entirely applied to its motion in a directly opposite direction, it would ascend in exactly the same proportionate distance, inversely, in each successive second; and would come to a state of rest at just the place from which it started, and in exactly the same number of seconds consumed in its fall. The initial Energy of Position, or Potential Energy, transformed into Energy of Motion, or Kinetic Energy, in its downward course, would have been completely restored at the termination of its upward course.

The ultimate effect upon a mass of matter of the acceleration or of the retardation of its motion, is the same, whether the motion be directly vertical or in any inclined direction, provided the altitude be the same. Consequently, the expenditure of kinetic energy required to raise such a body in any inclined direction would be equivalent to that required to raise it vertically to an equal height; though the total quantity of energy would have been expended more slowly, in proportion to the relatively greater distance over which that body had passed in its inclined ascent.

Sources and Causes of Resistance to Train Motion

In the application of these principles to train-service, other resistance than that of gravity must be considered. First, as to frictional resistance, which is due either to the sliding or rolling of two surfaces in contact, the effect of which is independent of the velocity or the area of contact, and depends solely upon the nature of the two surfaces and upon the pressure upon them, to which it is directly proportional. Friction may be external or between two bodies independently in motion, or internal, due to motion of parts within the body itself.

Internal friction in train-service is principally caused by the revolution of the axles in their bearings, or journal-friction.[2] Journal-friction is due to the interlocking of the molecules in the two surfaces in contact, and this resistance to the revolution of the axles absorbs a portion of the kinetic energy of the train, which is dissipated in heat. There is also an external friction between the wheel-treads and the rails. Atmospheric resistance is of three kinds: the head-resistance, due to pressure by the moving train; the skin-friction along the sides of the train; and the resistance due to the

[1] See Appendix VII, Note I.

[2] The internal friction in the locomotive is not here considered, being included in estimating its tractive power.

partial vacuum created between the cars and at the end of the train. These several effects of atmospheric resistance may be considered as varying with the speed and with the number of cars in the train.

There are yet other causes of train-resistance in the oscillations of the locomotive and of the cars, due to irregularities in the track and to the impact of the wheel-flanges with the rails as they swerve from side to side. The effect of these resistances is proportional to the momentum of the train. Though none of these several resistances to train-motion can be stated accurately as to quantity, as the effect of gravity can be, yet their total effect may be determined empirically by dynamometer-tests of the tender-drawbar-pull. With this statement of the causes and effects of train-resistance, consideration may be given to their practical application in train-service.

Means for Overcoming or Lessening Friction in Train Movement

It is the province of the Transportation Department to utilize in train-service the locomotives and cars provided by the Motive Power and the Rolling-stock Departments. The theoretical tractive power or duty of each class of locomotives is established in pounds and its equivalent in tons of gross train-loads, in accordance with the formulas given in Appendix II, Table XVIII. This equivalent is estimated for a straight, level and smooth track and, on such a track, the tractive power sufficient to overcome the inertia of a train should, under normal conditions, maintain that train in motion at a speed of between seven and ten miles an hour. The tractive power of each locomotive is further proportioned on the particular line or division upon which the train-service is conducted, in accordance with the "ruling grade," as set forth in the "rating-sheet." The ruling-grade is usually the maximum grade on a tangent as, on a properly located line, any curvature on the maximum grade is duly compensated for by an equivalent reduction in the gradient at that point.[1]

Assuming that, upon any division, the curvature has been duly compensated for, the grade-resistance may be accurately determined in accordance with the law of gravitation. As already stated, the retardation of motion is theoretically the same, whether that motion be vertically upward or in any inclined direction; provided that the altitude is the same. Consequently, the tractive power required to draw a train up any grade, in excess of what would be required upon a level at the same speed, would be equivalent to the power expended in raising the train vertically to an equal height. The excess of tractive power so required is the measure of grade-resistance, and amounts to 20 pounds per ton-weight of train on a one per cent. grade, and proportionately on other gradients.[2]

The frictional resistance can not be so accurately determined. Its most important element is journal-friction. Any increase of pressure on an axle-

[1] See Appendix VII, Note II. [2] See Appendix VII, Note III.

journal, within car-load limits, does not materially increase the journal-friction. The frictional resistance therefore, in an eight-wheel car, is virtually the same whether it be empty or loaded. Consequently, a train of twenty empty box cars offers the same resistance, as to journal-friction, that it would offer if the cars were loaded. Experimentally, this resistance is estimated at about nine pounds per ton-weight for an empty standard box car, at about four pounds per ton when fully loaded and, for a mixed train of empty and loaded cars, it is averaged at six pounds per ton.[1]

It is assumed that the journals are in normal condition as to lubrication, that the lubricating material is not chilled below 40° F., and that the journals are not heated above 100° F. With reference to lubrication, it may be stated that the character or composition of the lubricating material seems to be of less consequence than the fit of the bearing, or the manner in which that material is applied. Much more attention is paid to this matter in Europe than in this country. There, the lubrication is made with oil contained in a reservoir beneath the journal, to which it is applied by a pad fed with wicks. The box is dust-tight, the oil economically supplied, and a hot box is rarely seen. In the United States, this matter has received far less attention than it deserves. The journal-boxes are neither oil-tight nor dust-tight; the wastage of lubricating material is evident along the track and hot boxes are by no means unusual. Apart from the dangerous delays thus caused, and the possible accidents from broken journals, the draft upon the tractive power of the locomotive is materially increased and to no profit.

The track-resistance from the external or rolling friction between the wheels and the rails, may be regarded as proportionate to the weight of the train, and as sufficiently covered by the allowance for journal-friction. But this does not include the effects of oscillation, impact, or the wave of deflection, which vary greatly with the speed and weight of the train, and may be comparatively ascertained by dynamometer tests.[2] The effect of atmospheric resistance upon slowly moving freight-trains is almost negligible. Probably the most serious resistance is caused by leaving open the doors of box cars.

Rating and Tonnage Capacity of Locomotives

The several causes of resistance to train-motion which are to be considered in the construction of a locomotive rating-sheet may be summed up as follows:

[1] The results of recent tests are given in Appendix VII, Note IV. With rolling-stock of modern construction, the frictional resistance of a fully loaded train may be safely assumed at 4.65 pounds per ton, at speeds up to ten miles an hour.

[2] For a more extended reference to this subject, see Chapter V, Part II, pp. 236–238.

1. Journal-friction, varying from 4 pounds per ton-weight of loaded train to 9 pounds per ton-weight of empty train, exclusive of locomotive and tender.

2. Track-resistance, covered by allowance for journal-friction in slowly moving trains.

3. Atmospheric resistance, virtually negligible in slowly moving trains.

4. Grade-resistance at 20 pounds per ton-weight of entire train for a 1 per cent. grade, and proportionately for other gradients.

The practical allowances for the first three causes of resistance apply under all conditions of train-service, whether on a straight and level track or on a gradient compensated for curvature.[1] The effect of journal-friction upon the tractive power of a locomotive is greatest in starting a train, which is often only accomplished by "taking up the slack" and thus successively overcoming the inertia of each car in the train. This initial resistance has been found to reach 20 pounds per ton-weight of the train, but is only momentary.[2] As soon as the train is under way, the resistance from journal-friction rapidly diminishes to its normal amount, which is usually attained in a distance of five-eighths of a mile and between the speeds of seven and ten miles an hour.[3]

Within this range of speed, the normal tonnage-capacity of a locomotive is determined by dividing its tractive power, available at the tender-drawbar, by the assumed resistance of a train of fully loaded cars on a straight and level track. From this result, a reduction is to be made for the resistance over the ruling-grade on the division. In practice, it is not safe to utilize more than 90 per cent. of this rating, in order to provide for starting a loaded train when stopped on the ruling-grade. In extremely cold weather, there should be an additional reduction of 10 per cent. Furthermore, locomotives are not always in condition to work up to their theoretical capacity. For all these reasons, the allowance to be made from the rating-sheet for each locomotive in its class must be left, in a great measure, to the discretion of the yardmaster and of the dispatcher, who should be familiar with the local conditions. In fact, the economic conduct of freight-train service is practically dependent upon the efficiency of these officials and of the firemen.[4]

Use of "Pushers"

There are several ways of increasing the average train-load over a division. Where there is an exceptional gradient in excess of the ruling-grade, or where the maximum gradient is concentrated at a summit, the

[1] For resistance from uncompensated curvature, see Appendix VII, Note III.

[2] The use of sand in starting increases the track resistance; it should not be used over an interlocking plant.

[3] See "Railway Location," Wellington, p. 512.

[4] For further information on this subject, see Appendix VII, Notes IV to VI.

assistance of a "pusher" (or "bank-engine," in British railway-parlance) is of advantage for this purpose. The type of locomotive for a pusher, as to wheel-arrangement, should be suitable for running backward down grade, and its tractive power should be limited to the exceptional grade-resistance to be overcome by a locomotive with the average train-load. The use of pushers with excessive tractive power is not only an unnecessary expense, but it also tends to increase the size and weight of the regular road-locomotives beyond the requirements of the normal freight-traffic. The average train-loads on a division may be sensibly increased by the use of pushers on intermediate maximum grades. This is done on intermediate gradients of 0.4 per cent. on the Hudson River Division of the New York Central Railroad, which is on a level for nearly 95 per cent. of its length. The trains should be kept far enough apart to avoid detention in waiting for the return of the pusher, or the unnecessary use of a second locomotive for this purpose.[1] Where the freight-trains are not sufficiently frequent to keep a pusher profitably employed on an exceptional grade, resort is sometimes had to the expedient of "doubling the grade." This practice is of questionable advantage. The presence of part of the train unattached to a locomotive on the main line is an obstruction to the traffic and a probable cause of accidents.

The growth of traffic on a single-track line is frequently accompanied by concentration of train-movements on certain divisions, requiring additional passing-points and consequent delays in train-service. This condition may be somewhat relieved by consolidation in heavier trains drawn by two locomotives. This plan calls for long lap-sidings, which are gradually lengthened into running-tracks. Such measures are but palliative in the postponement of double-track operation.[2] Double-headers are also used on double-track lines, operated under block-signals, for reducing the number of trains in blocked sections and thereby expediting train-movements. It is however preferable to duplicate trains, where the first section can be efficiently protected against the following section.[3]

Tonnage Distribution in Trains. Tonnage Rating

The difficulty in adjusting the tonnage of a train to the rated capacity of a locomotive, may be inferred from the following statement of the factors which enter into its determination; viz.

1. Rate of ruling-grade.
2. Degree of uncompensated curvature.
3. Car-journal lubrication.
4. Average gross weight per car.

[1] See "Railway Location," p. 591. [2] See Chapter V, Part II, p. 251.

[3] Double-heading is a current practice in Europe, even for the fastest trains; being necessitated by the use of light locomotives, or in order to reduce the number of trains in the blocks.

5. Condition of rails.
6. Weather conditions.
7. Character of traffic on the line.
8. Running time allowed.
9. Location and extent of passing-tracks.[1]

From this statement it will be seen that the rating-sheet of a locomotive is only of value as a basis for the establishment of its maximum capacity on slowly moving and fully loaded trains, and that the reduction to be made in its application in practical service is governed by conditions which are largely empirical, and that it could be more satisfactorily established, with reference to any particular division or service, by occasional dynamometer-tests.

At intermediate junctions on a division, the transfer of tonnage may be provided for with economy in train-service by a judicious distribution of loaded cars among the through trains. Loaded cars taken into a train at one terminal are dropped at the junction and other loads there taken on for the other terminal. There is also what is known as "turn-around" service at intermediate points where a marked change occurs in the ruling-grade. On the lighter part of the line, the tonnage-rating may be increased while in the farther direction it must be diminished; or lighter locomotives may be employed on the easier grades.

The same quantity of draw-bar pull may be absorbed in moving a heavy train at a low rate of speed, or a lighter train at a higher rate. Although the tonnage rating-sheets are based on a speed of ten miles an hour, it is not practicable to restrict all classes of traffic to that rate of speed and meet the requirements for social efficiency. Live-stock, perishables and other commodities of a special character are, therefore, moved at higher speeds. There are also economic reasons for a higher rate of speed for freight-trains. On lines with dense passenger-traffic, lighter loaded freight-trains may move at higher speed with fewer passing-points with passenger-trains, and with a saving of time at sidings on the road. This is the usual practice in Great Britain and, with the increasing pressure for legislative regulation for shorter hours of labor and the frequent occurrence of car-shortage, it is probable that a similar course will be pursued in our own railroad-operation, wherever the passenger-traffic is of commensurate importance.

It has been determined experimentally that, "with long and heavy trains it requires less fuel with the same engine to run trains at 18 to 20 miles an hour than at 10 to 12 miles an hour."[2] The consumption of fuel also depends, to a considerable extent, upon the time that a locomotive is on the road between terminals. The loss

[1] See "Freight Terminals," p. 155.

[2] "Experiments on Lake Shore & Michigan Southern Railroad," by P. H. Dudley. Trans. Am. Soc. C. E., October, 1876.

of energy by external radiation of heat is continuous, and is in proportion to the difference between the temperature within the boiler and that of the atmosphere. The percentage of loss between the boiler-pressure and the cylinder-pressure, which is some 15 per cent., and the waste of fuel while standing in sidings at passing-points, are more affected by the lapse of time than by the increased train-resistance, which is also lessened to some extent by the effect of momentum at higher speeds. Other favorable factors are now available in the greater tonnage-capacity of cars, the stronger draft-gear and the general use of quick-action air-brakes.

In passenger-train service, economic efficiency becomes subordinated to social requirements. The capacity of the carriages may be established as to the number of occupants, but travelers can not be herded like cattle, nor can the carriages be marshaled in trains to conform to the rated power of locomotives. Speed supplants tonnage as the ruling factor in efficiency, and that property of matter known as momentum assumes far greater importance than in freight-service.[1]

Speed Requirements. Velocity Resistance

The speed required in passenger-train service is only to be attained by tractive power considerably in excess of that required for overcoming the inertia of the train in starting, and, to maintain high speed, the evaporative capacity of a passenger-locomotive must be correspondingly greater in proportion to its tractive power than with a freight-locomotive. After the train is in motion and has acquired the speed due to the initial expenditure of energy for that purpose, any additional draft of tractive power would have the sole effect of accelerating the speed of the train, on a straight and level track. The effective draw-bar pull, however, decreases rapidly with acceleration of velocity. For this reason, an additional locomotive is frequently attached to a heavy, high-speed passenger-train.[2] Conversely, a slight reduction of velocity at high speed considerably increases the effective draw-bar pull.

The tractive power of a locomotive is not materially affected by the ascent of moderate grades. Where such grades occur as undulations, the average speed is sustained on the ascending grades by the momentum accumulated on the preceding descent, if the average grade of the undulations approximate a level, in which case the normal tractive power is efficiently applied in the ascent, and may be economically diminished in

[1] Momentum is the Energy of Motion, as Inertia is the Energy of Position. It is the product of the mass of a body multiplied by its velocity. While the velocity is uniform, the momentum is directly proportional to the mass or quantity of matter in the moving body. While the mass remains unchanged, any change in momentum is due to a corresponding change in velocity. Its quantity may be measured in foot-pounds per second, and its sum increased, maintained or diminished by an alteration in the factors of which it is a product.

[2] On a level, straight track, the draw-bar pull of a locomotive of 800 horse-power is virtually exhausted at a speed of 70 miles an hour. See Appendix VII, Note V.

the descent. The energy thus developed is measured as work, in foot-pounds per second.[1] This work is performed in overcoming the resistance offered by ascending grades, in rounding curves by the friction of the rolling wheels against the rails, by inequalities in the track and by the internal friction of the axles in their bearings. Resistance from any of these causes must diminish the momentum of a train, unless its speed is maintained by a continuous absorption of energy in tractive power. It is necessary to keep these propositions in mind in any discussion of the economic application of tractive power in passenger-train service.

But other causes of train-resistance, which are negligible in their effect upon slowly moving trains, engender more serious consequences at high speeds; atmospheric resistance, for instance, and the resistance arising from oscillations and concussions on the track. The rolling-friction between the wheels and the rails is materially increased by irregularities in the track, whether in line or in surface, and proportionately with the increase of momentum at high speeds.

It is generally assumed that velocity-resistance varies with the square of the velocity, somewhat in accordance with the formula, $R=FV^2+C$ in which F = friction, V = velocity and C = curvature. It is not possible to separate this aggregated velocity-resistance into its constituent elements including those due to the resistance of the track and of the atmosphere. Experimentally, it has been shown that the effect of track-resistance is the greater of the two. But at high speeds, the skin-friction of the train and the partial vacuum created at the rear of the train and between the cars increases the resistance proportionately more than the head-resistance is increased. The introduction of vestibuled trains seems to eliminate the partial vacuum between the cars.

The effect of vertical alignment varies with changes of gradient, as to degree, in accordance with the immutable law of gravitation and with the ascending or descending direction of the train. Even on a straight, level and smooth track, the alternating and unbalanced impulses in the steam-cylinders induce changes in horizontal direction, which are as incessantly restricted by contact of the wheel-flanges with the rail. There is a consequent impact and oscillation that vary with the train-momentum, and with the accompanying wave of deflection in the track-surface. Retardation from wheel-and-rail contact increases with increasing curvature until the permissible limit has been reached. The velocity of the train is further retarded by the friction of the wheel-flanges against the sides of

[1] The work done in running a mile by a locomotive with tractive power of 20,000 pounds is $20{,}000 \times 5280$ feet $= 105{,}600{,}000$ foot-pounds. Such a locomotive, in running a mile in four minutes, develops horse-power equal to $\frac{105{,}600{,}000}{33{,}000 \times 4} = 800$ H. P., or, running a mile in five minutes, $\frac{105{,}600{,}000}{33{,}000 \times 5} = 640$ H. P.

the rail-heads and by the slipping of the wheel-treads upon the top-surface of the rail around curves; also by the journal-friction and the internal friction of the locomotive machinery.

The rapid decrease of draw-bar pull at high speeds may be neutralized to some extent by a judicious use of the momentum stored up in the train, and especially on undulating grades. In "drifting," or descending a grade without steam or braking, a train acquires accelerated velocity in proportion to the degree of gradient. Starting from a state of rest, at the top of a 0.5 per cent. grade, it should attain a speed of 25 miles an hour in the distance of 222 feet.[1] A train approaching the foot of such a grade at a speed of 50 miles an hour has attained momentum sufficient to lift it vertically 88.75 feet before coming to a state of rest, and to carry it up a 1 per cent. grade for a distance of 8875 feet.[2] The initial rate of speed could be maintained for this distance by the locomotive's supplying only the tractive power which had been required to attain the same rate of speed on a level track.

There is a degree of slope at which the train-resistance would just balance the acceleration of gravity and a train remain at a state of rest. This is the "Grade of Repose." On such a grade, a train should theoretically descend continuously at its initial rate of velocity, according to the First Law of Motion. In this state of equilibrium, any accession of tractive power would serve entirely to increase that velocity. Conversely, on an ascent, the tractive power would have to be increased sufficiently to overcome the grade of repose, in order to maintain the initial rate of velocity. It follows that any ascending grade is equivalent, in its retarding effect upon the velocity of a train, to the actual rate of gradient plus the grade of repose, and that the accelerating effect of a descending grade is equivalent to that of the actual rate of gradient minus the grade of repose.[3]

The use of the momentum of the train in freight-service to eke out the over-rated power of the locomotive is a practice of questionable value. It encourages excessive speed on descending grades and is a hindrance to train-movements when an emergency-stop is made on an ascent. The effect upon long freight-trains of sudden changes from a descending to an ascending grade frequently causes a train to part because of broken couplings, though this trouble has been diminished by the general in-

[1] For velocity of "drifting" trains, see Appendix VII, Note XII.

[2] See Appendix VII, Note XI.

[3] A train resistance of 7 pounds per ton would be equivalent to a grade of repose rising 7 feet in 1000, or of 0.7 per cent., which is about 37 feet to the mile. As the train resistance in pounds per ton varies with the velocity of the train and with its length, the grade of repose varies accordingly. On account of the initial journal-friction, which is equivalent to about 20 pounds per ton, no car will start of itself on a 0.7 per cent. gradient, or of 37 feet to the mile; but will generally do so on a gradient of 1.1 per cent. or of 58 feet to the mile. See Appendix VII, Note X; and also "Railway Location," p. 341.

troduction of closely-coupled vertical-hook couplers, with stouter draft-gear, and can be entirely eliminated by the intervention of vertical curves at the change of grade.

Brake Action and Brake Efficiency

While the mass of a moving body remains unchanged, its momentum can only be diminished by a decrease in its velocity. With the withdrawal of tractive power, the speed of a train is decreased either by the resistance due to gravity, as in ascending a grade, or in its transformation into heat by impact or by frictional resistance. This negative action may be supplemented by brake-friction for the purpose of acquiring positive control over the motion of a train.

In the application of brakes, the momentum of the train is affected indirectly, through the transformation of the rotary motion of the car-wheels into heat. As this frictional resistance affects only the wheels to which the brakes are applied, the efficiency of the brakes depends *primarily* upon the proportion of the weight carried by the braked wheels to the total weight of the train. With increasing pressure of the brakes, a point is reached at which the rotary motion of the wheel is entirely arrested, and its rolling-friction upon the rails becomes changed to sliding-friction, or "skidding," to the injury of both the wheel and the rails. The maximum brake-pressure should, therefore, be limited to two-thirds of the load on the braked wheel. Consequently, the maximum efficiency of the brakes on all the wheels in a train can not exceed that proportion of the total weight of the train, as measured by the pressure in pounds per ton required to skid all the wheels. As the rotary momentum of the wheels varies with the swiftness of their revolution, it was formerly assumed that the brake-pressure sufficient to arrest their revolution would decrease proportionately, and that the continued efficiency of the brakes could only be maintained by a corresponding decrease of pressure upon the wheels. But the experiments made by Mr. George Westinghouse and Sir Douglas Galton, in 1878, proved that the pressure sufficient for skidding depended upon the extent of adhesion to the rails.[1] The speed of the train is a controlling factor as to the time and distance within which it is practicable to bring a train to rest by brake-friction on a level track. This problem is further affected, on an ascending or descending grade, by the influence of gravity; and the retarding effect of the brakes may be assisted, in an emergency, by reversing the action of steam in the cylinders of the locomotive.

The maximum efficiency of brake-friction, as theoretically established, is far from being attainable by means of the hand-brake. Its application is progressive, according as the brakes are applied by one or more persons. Its efficiency further depends upon the vigor of the brakeman, as well as upon the leverage of the brake-gear, and is empirically established as

[1] See Chapter IV, p. 109.

from 2½ to 5 per cent. of the load on the braked wheels. Hand-brakes are not capable of the simultaneous action required of an effective train-brake, for which reason, except as applicable to the movement of individual cars, they have been superseded by power-brakes operated by compressed air. In connection with closely-coupled draw-gear and improved brake appliances, the quick-acting electro-pneumatic air-brake acts upon a train as upon a single mass and, by this means, the maximum efficiency of brake-friction has been closely attained. The air-brake apparatus is used to advantage in moving a train backward, by attaching to the rear end of the air-pipe a section of hose provided with an air-valve to control the speed of the train and a signal-whistle, which are operated from the rear platform.[1]

A train of twelve steel passenger-cars, weighing in all 920 tons, develops a kinetic energy of over 100,000 foot-tons at a speed of 60 miles an hour; yet with the quick-acting brakes, it can be stopped on a level track in about 21 seconds in a distance of 1000 feet. The transformation of this tremendous energy into heat is the equivalent of about 20,000 nominal horse-power. This statement aids in forming a conception of the work done in stopping such a train, sufficient to lift the whole train vertically 128 feet in 21 seconds, or to maintain it at full speed for six miles on a level track.

The use of electric traction has introduced some exceptional problems in connection with transportation-efficiency. These have been, for the most part, discussed in the chapter on Motive Power. One of especial interest relates to "regenerative braking," or the restoring of energy to synchronous motors from the momentum of trains on descending-grades.[2] There is said to be a tendency in electric operation to overload the heating capacity of the motors by quickening the schedules, increasing the number of stops or adding trailers to the trains. On the Swiss electric railways, with a permanent draw-bar pull of 22,046 pounds, the maximum speed on falling gradients of 27 in 1000, or of 137 feet to the mile, is 40.4 miles an hour for passenger-trains. On similar rising gradients, a speed of 31 miles an hour is attained with trains weighing 300 tons, and of 28 miles an hour for freight-trains of that weight.

Reduction in Train-weight. Efficiency in Train-loading

The application of tractive power in train-service has now been followed as a cycle of traction from a state of rest through one of motion to its return to a state of rest. There is yet another aspect of it as a phase of economic efficiency. The profitable application of tractive power is not to be measured by the total amount absorbed in keeping a train in

[1] For the development of power-brakes, see Chapter IV, pp. 105–112.
[2] See Chapter III, p. 84.

motion. That part which is required to keep the dead-weight of the cars in motion earns no money for the railroad company. To whatever extent the unproductive weight can be diminished, to that extent the productive weight may be increased by the absorption of the same amount of energy in tractive power and without reduction in the rate of speed. It is therefore an element of the efficient use of tractive power, from a commercial point of view, that the dead-weight of a train shall be maintained at the lowest point consistent with the safety of its contents.

The foundation of economic efficiency in freight-service is the utilization of each car to its fullest capacity, and the first step in this direction must be taken at the points of origin of the traffic. In mineral districts, these traffic-points are scattered along the line or division, or on short branch-lines, and are served by special trains which distribute empty cars as required and deliver them loaded at the farther terminal, as the tractive capacity is attained. In a similar way, in agricultural districts, grain-cars are loaded at station-elevators, cotton at local presses and perishables at cold-storage stations. Forest-products are likewise taken from the mill-sidings and petroleum-products from the refineries. The above-mentioned products constitute by far the greater part of the tonnage of our railway-system and, in order to insure full loading, a considerable and expensive train-service is required before they become incorporated in the general volume of traffic. This is also the case with the distribution and collection of cars in large cities with several freight-terminals. Even where a charge is made for such service, it is based rather upon the expectation of profit to be derived from the subsequent haul in through-trains than upon its actual cost.

The current demand for cars at points of origin and the sources whence they may be obtained must be ascertained sufficiently in advance for the cars to be promptly supplied. This information must cover the ownership and the character of the available equipment. It is desirable to keep the "home" cars upon the company's own line, and to load "foreign" cars in a direction homeward. The suitability of the empty cars for the desired purposes must also be kept in view. As there are about eighteen kinds of freight-cars, it is necessary to know the character and location of each of thousands of cars, whether they are loaded or empty, to have this information collected by telegraph or telephone, and to have it collated daily and promptly in the office that controls the distribution of freight-equipment. This result can be secured only by a systematic method under intelligent supervision.[1]

When the demands for cars have been supplied, the next step is to insure that they shall be loaded to their normal capacity. In a committee report of the American Railway Association, it was reported that in 1909 not more than 60 per cent. of the total car-capacity had been utilized, and

[1] See "Economics of Railway Operation," Byers, pp. 485–492.

that the increases in the individual car-capacity had not been accompanied by an increase in the average load per car.[1] This statement does not apply to the mineral traffic, which constituted 57 per cent. of the total tonnage in 1914. It may be assumed that the owners of the private refrigerator and tank-car lines utilize them to the best advantage with their own products, and that the same may be said of the flat cars which are principally used for lumber.

Excluding open-top, refrigerator, tank, stock, and flat cars, as being practically fully loaded at points of origin, there remained in 1914, 1,043,796 box cars, or about 40 per cent. of the total equipment of the railway companies, with a nominal tonnage capacity of 36,365,350 tons, or an average of 35 tons per car.[2] The total tonnage from points of origin in 1914 was 1,094,123,895 tons. Deducting the tonnage in products of the mines, of animals and of forests, amounting to 764,092,081 tons, there remains a tonnage of 330,031,814 tons, which represents approximately the box-car freight in that year.[3] This tonnage could have been moved in about nine trips of the total box-car equipment, making a trip about every six weeks. From this statement, a conception may be formed of the extent to which box cars are light-loaded or detained at terminals.

In the matter of light-loading, consideration must be given to the character of the commodities to be transported. Many of them fill the capacity of a car for space before its limit for weight has been reached.[4] The minimum allowances in classification-rates contribute to light-loading and have not been increased with the larger tonnage capacity of box cars. Light-loading is also preferred to starting a foreign car homeward empty. The average car-load varies greatly with the physical or industrial environment in which a railroad is operated, as is shown in the Transportation Statistics for 1914, in Appendix VII, Table XVIII. The maximum of 46 tons was attained on the Butte, Anaconda & Pacific Railway, a mineral road with 26 miles of main line and 36 miles of branches. The minimum loading of 10 tons was on the Northwestern Pacific Railroad, with a main line of 281 miles and 182 miles of branches. Typical car-loadings on important lines in different regions of the United States are given in Appendix VII, Table XVI.

Box-car freight, for the most part, passes through the freight-houses to be weighed, billed and sorted for loading. Each shipment involves the services of a receiving-clerk, a weigher, freight-handlers, truck-hands, a tally-man and stevedores. The monthly tonnage at some thirty stations averaged 1,000,000 tons of track-freight and 400,000 tons of house-freight.[5] At the Wood Street Station in Chicago of the Chicago & North Western

[1] For other instances, see Appendix VII, Tables VIII and XIV.
[2] Appendix III, Table III. [3] Appendix VI, Table XIV.
[4] Appendix VII, Note XIII.
[5] "Economics of Railway Operation," p. 517. Track-freight is loaded from wagon directly into cars; house-freight is placed in, and taken from, storage.

Railway, on an average, 130 cars are loaded daily with from 15,000 to 20,000 packages. In the large cities, the requirements of the local traffic induce the establishment of many separate freight-stations. The New York Central Railroad has eight in New York City. The Pennsylvania Railroad has seven in Pittsburgh and thirty-one in Philadelphia. In Boston, the New York, New Haven & Hartford Railroad has twelve and the Boston & Maine Railroad has fifty.[1]

Light Loading and "L. C. L." Freight

The economical handling of "L. C. L." freight (less-than-car-load lots) is a troublesome problem. If such freight for different stations is loaded into one car, the train is delayed in discharging it, even though it be loaded carefully in station order. If the shipments for each station be loaded separately, there is a waste of tractive power and of car-mileage in handling partially loaded cars, a loss of time in setting them out of the train, and a considerable loss in the use of cars so employed. Shipments of this character are therefore seldom moved in through-trains. Between way stations on the same division, they are usually handled in and out of the "peddler-car" by the crew of the way-freight train. If destined to or beyond the end of the run, they are loaded together in a "straight car" to be handled at the terminal of the division or, at junction points, at the transfer station.[2] Cars with package-freight should be placed next to the caboose, so that the small lots may be unloaded at the freight-house while the fully loaded cars are being set off from the head of the train. It becomes exceedingly difficult to secure maximum loading with minimum delay for shipments of package-freight on roads with many side-lines and junction points. Elaborate instructions are issued for this purpose.[3]

L. C. L. freight is the least profitable class of traffic. This is not only as to train-movements but also with respect to its receipt at the point of departure, its handling and billing and the care required in loading it; and again, as these operations are reversed at the point of delivery. It is with this class of freight that the claims for loss and damage are proportionately great and expensive of adjustment. Special attention to these matters by committees of the American Railway Association has resulted in codifying in great detail the rules governing them.[4]

The conditions prevailing on the British railways, where the miscellaneous traffic includes much of our perishable and express business, are exemplified in the following statement:

[1] "Freight Terminals," p. 276.

[2] See Chapter V, Part II, p. 282.

[3] See "Freight Terminals," p. 317.

[4] For further information on this subject, see "Economics of Railway Operation," pp. 517–538; and "Freight Terminals."

LOADING OF MISCELLANEOUS SHIPMENTS

	GREAT NORTHERN RAILWAY	LONDON & NORTH WESTERN RAILWAY
Total shipments	985	6,201
Total packages	4,427	23,607
Total weight, pounds	273,800	2,029,440
Average weight, per shipment, pounds	278	327
Average weight, per package, pounds	62	86
Number of cars used	72	379
Number of destinations	53	720
Average load, tons (2000 pounds)	1.83	2.67

Car-capacity, 11.2 tons. Empty weight, 6.75 tons.

The average loading on the Great Northern Railway was but 16 per cent. of the car-capacity, and 24 per cent. on the London & North Western Railway. The 72 car-loads on the Great Northern Railway could have been loaded in 12 cars, and the 379 car-loads on the London & North Western Railway in 91 cars. The saving, in the former case, of 60 cars and of 405 tons of dead-weight would have amounted to 65 per cent. of the actual gross train-weight; in the latter case, of 288 cars and of 1937 tons of dead-weight, amounting to 54 per cent. of the actual gross train-weight. Similar experience on railroads in the United States is given in Appendix VII, Table XV. In an inspection of ten cars, taken at random, they were found to be loaded to less than one-half of their total weight-capacity of 940,000 pounds, and by no means to their space-capacity. Several plans have been proposed for reducing the proportion of light-loading from this cause. The American Railway Association has endeavored to restrict the receipt of L. C. L. freight for specific destinations on certain days in the week, with the object of concentrating the shipments for each destination in the same car. A more extended use of mixed trains, as suggested in Chapter VI, page 313, seems worthy of consideration for this purpose.

TRAIN MAKE-UP AND AVERAGE CAR-LOAD

In classifying cars for train-movements, trains may be made up with either of the following objects in view:

1. To move the greatest net tonnage with a locomotive of a given tractive power.

2. To move the greatest net tonnage in a given period of time with the same locomotive.

These are economic applications of tractive power. Or,

3. To move certain commodities at higher speed to meet commercial requirements.

In making up trains, the tonnage of locomotives, as classified in the rating-sheet, must be modified to meet these varying requirements. The actual condition of each locomotive and the prevailing weather-conditions have also to be considered so that, to insure efficient service, the tonnage of each train must be left somewhat to the discretion of the experienced yardmaster. The frictional resistance of an empty car is about double that of a loaded car, weight for weight. This fact is to be kept in mind in making up a mixed train; since the greater the number of cars in a train, the greater is the resistance of such a train of the same gross weight. This is especially of importance in making up fast-freight trains of cars that are variously loaded in proportion to their nominal capacity.[1] Cars should also be so placed in trains as to facilitate their distribution in accordance with their respective destinations, thus saving much intermediate delay in the re-arrangement of trains. In the movement of time-freight, that is, of commodities to be delivered at distant destinations within a definite period, this becomes an important matter.

The relative position of empty cars in a train is supposed by trainmen to affect the train-resistance. They think that empty cars should be at the rear of the train. However this may be, the resulting shock to a long train should be less when brakes are suddenly applied, or when steam is shut off on a descending grade, if empty cars are not next to the locomotive. This effect has been lessened with the general use of close couplers and quick-action brakes. Notwithstanding these improvements, it is questionable whether the length and weight of heavy freight-trains has not about reached a practical maximum with trains of eighty to a hundred fully loaded cars drawn by locomotives of weight and power sufficient to take such trains up a 1 per cent. grade at a speed of ten miles an hour.

It is of the first importance that trains should be "made up" to the full tonnage-capacity of the locomotives to be attached to them. It is with this object in view that the freight-locomotives on a division are classed on a rating-sheet. In the earlier development of this plan, locomotives were rated by the number of loaded cars, whether fully loaded or not; two empty cars being rated as one loaded. With the introduction of cars of greater capacity, it might occur that a gross tonnage of 2000 tons would vary between 27 and 65 car-loads. The tonnage-rating was subsequently made from the way-bills, with closer approximation to the tractive power of the locomotive. The estimated tonnage-rating was based on cars of 40 tons gross weight, so that a locomotive with 36,000 pounds draw-bar pull might be rated, to suit the ruling-grade on a division, at 2000 tons in a train of fifty of such cars.

As any pressure on an axle-journal, within reasonable limits, does not materially increase the friction, the frictional resistance of a car is virtually the same whether it be empty or loaded, though the resistance offered by the car per ton will vary with the gross weight of the car. The total re-

[1] See Appendix VII, Note IV.

sistance of the train will vary according to the gross weights of the several cars of which it may be composed and, consequently, as to whether they are fully or but partially loaded. The economic results of hauling trains of cars of various nominal capacities and with full or partial loading, as discussed in Appendix VII, Note XIV, may be stated as follows: With the same draw-bar pull, the greater the capacity of the car, the fewer may be the cars in the train and the greater will be the net tonnage; while the lighter the cars are loaded in proportion to their capacity, the greater will be the waste of tractive power.

In actual operation, there is a wide variation in the make-up of trains, with respect to tonnage and to the relative proportion of loaded and empty cars in a train as will be seen by reference to the Transportation Statistics for 1914, in Appendix VII, Table XVIII. The heaviest average car-load and train-load and the greatest number of loaded cars and of total cars in a train, were in the Eastern District; with averages of 23.4 tons per loaded car, and of 557 tons per train of 23.8 loaded and 12.0 empty cars. The Southern District averaged 21.3 tons per loaded car and 427 tons per train of 20 loaded cars and 10 empty cars. The Western District averaged 18.4 tons per loaded car and 472 tons per train of 23.2 loaded and 10.0 empty cars.

In the Eastern District, the maximum average car-load of 44.7 tons was on the Bessemer & Lake Erie Railroad, and the maximum average train-load of 1162 tons was on the Pittsburgh & Lake Erie Railroad, with an average haul of 63 miles. The maximum average number of cars per train was 34 loaded and 17 empty on the Lake Shore & Michigan Southern Railway. The minimum average in all of these respects was on the Atlantic City Railroad, of 13.2 tons per loaded car and 141 tons per train of 11 loaded and 4 empty cars, with an average haul of 23.8 miles.

In the Southern District, the Virginian Railway averaged a car-load of 45.5 tons and a train-load of 1409 tons in a train of 31 loaded cars and 26 empty, on an average haul of 354.77 miles; a performance unequaled elsewhere in the United States, and probably in the world. On the other hand, the Florida East Coast Railway averaged a car-load of 9.3 tons and a train-load of 158 tons in an average train of 17 loaded and 11 empty cars on an average haul of 164 miles; these conditions being due to a traffic principally in perishables in refrigerator-cars.

The heaviest average car-load in the Western District, and in the United States, was 46 tons on the Butte, Anaconda & Pacific Railway on an average haul of 27 miles, and the heaviest average train-load was 1108 tons on the Duluth, Messaba & Northern Railway on an average haul of 73.68 miles. The Great Northern Railway averaged a train of 32 loaded and 14 empty cars on an average haul of 224.59 miles.[1]

[1] See Appendix VII, Table XIX.

Train Mileage Statistics

In the Eastern District, the greatest mileage per mile of line was on the Philadelphia & Reading Railway, of 8297 freight-train-miles and 6013 passenger-train-miles, a total of 14,310 train-miles, and an average of 22.7 freight-trains and 16.5 passenger-trains, or 39.2 trains per day on a line-mileage of 1120 miles of main lines and branches. This freight-train mileage was exceeded on the New York, Chicago & St. Louis Railroad, which averaged 9679 miles with 26.5 trains per day on a line-mileage of 567 miles. There was an average of 37.7 passenger trains per day on the Long Island Railroad on a line-mileage of 398 miles. The transportation business of New England is handled almost wholly by two railroad corporations, the Boston & Maine and the New York, New Haven & Hartford, with nearly equal line-mileage of 2302 miles and 2003 miles, respectively; equal freight-tonnage of 24,752 tons and 24,996 tons; but unequal passenger-mileage of 896,081 miles and 1,600,476 miles respectively. As between the four trunk-lines, the train-performance is as follows:

Average Train Performance. Trunk Lines. Eastern District. 1914

	Baltimore & Ohio	N. Y. Central & H. R. R. R.	Pennsylvania R. R.	Erie R. R.
Line-mileage	4,478	3,756	4,084	1,988
Per Mile of Line				
Freight-train mileage	4,743	5,414	7,414	5,389
Passenger-train mileage	3,726	7,064	6,211	4,565
Total	8,469	12,478	13,625	9,954
Per Day				
Freight-trains	13.0	14.8	20.5	14.5
Passenger-trains	10.2	19.3	16.9	12.5
Total	23.2	34.1	37.4	27.0

In the Southern District, the Richmond, Fredericksburg & Potomac Railroad averaged a passenger-train mileage of 8756 per mile of line with 24 passenger trains daily, and a total train-mileage of 15,517 miles with an average of 40.8 trains daily; a performance unequaled elsewhere in the United States, though on a line-mileage of but 88 miles. The greatest average freight-train mileage in this district was on the Cincinnati, New Orleans & Texas Pacific Railway, 7958 miles on a line-mileage of 337 miles. As between the principal trunk-lines in this district, the train-performance is as follows:

AVERAGE TRAIN PERFORMANCE, SOUTHERN TRUNK LINES, 1914

	SOUTHERN	ATLANTIC COAST LINE	SEABOARD AIR LINE	LOUISVILLE & NASHVILLE	ILLINOIS CENTRAL R. R.
Line-mileage	7,033	4,646	3,084	4,937	4,767
Per Mile of Line					
Freight-train mileage .	2,240	1,833	1,837	3,645	3,859
Passenger-train mileage	2,611	1,843	1,843	2,156	2,765
Total	4,851	3,676	3,680	5,801	6,624
Per Day					
Freight trains	6.1	5.0	5.0	10.0	10.6
Passenger trains . . .	7.2	5.1	5.3	6.0	7.6
Total	13.3	10.1	10.3	16.0	18.2

In the Western District, the Chicago & Alton Railroad averaged a passenger-train mileage of 3353 miles per mile of line with 9.2 trains daily, and a total train-mileage of 6536 miles with 17.6 trains daily on a line-mileage of 1033 miles. The greatest freight-train mileage was on the Duluth & Iron Range Railroad of 3546 miles with 9.7 trains daily on a line-mileage of 282 miles. As between the Transcontinental lines, the train-performance is as follows:

AVERAGE TRAIN PERFORMANCE, TRANSCONTINENTAL LINES, 1914

	CHICAGO, MILWAUKEE, & ST. PAUL	ATCHISON, TOPEKA, & SANTA FÉ	GREAT NORTHERN	SOUTHERN PACIFIC	NORTHERN PACIFIC	UNION PACIFIC
Line-mileage	9,684	8,346	7,780	6,457	6,325	3,614
Per Mile of Line						
Freight-train mileage	2,044	1,697	1,244	1,522	1,453	2,141
Passenger-train mileage	1,814	2,218	1,603	3,247	1,900	2,808
Total	3,858	3,915	2,847	4,769	3,353	4,949
Per Day						
Freight trains . . .	5.6	4.6	3.4	4.2	4.0	5.9
Passenger trains . . .	5.0	6.1	4.4	9.0	5.2	7.7
Total	10.6	10.7	7.8	13.2	9.2	13.6

LARGE CARS AND FAST-FREIGHT TRAINS

The investment in cars of large capacity and the cost of maintaining them, are relatively less in proportion to tonnage; while they afford increased facility in train-movements, because of the shorter length of trains of equal weight. A train of 30 cars of 50 tons' capacity with gross weight of 2010 tons, as compared with a train of cars of 30 tons' capacity and of equal gross weight, will carry 1500 tons net weight as against 1307 tons, and the train will be shorter by 500 feet.

The economic application of power to net tonnage principally affects the transportation of the mineral-products which constitute the larger proportion of railway traffic and which are moved at a slow speed. It does not follow that this is the most efficient mode of transportation when the element of time is taken into consideration; for, when the volume of traffic is great, a larger tonnage may be moved in a given period by quickening the speed of the train. Other reasons for the opinion that the economic rate of speed for heavy trains is over ten miles an hour, have been stated already in this chapter.[1]

There are commercial inducements for moving certain commodities at higher rates of speed than are warranted by an economic application of tractive power. As these commodities occupy a much greater space than minerals, in proportion to their weight, they are hauled in separate trains; as fast-freight trains, time-freight trains, live-stock trains and refrigerator-trains. The fast-freight trains originated in the period of fierce competition between the trunk-lines for the west-bound merchandise-traffic from the North Atlantic ports, with a separate equipment and organization on each of the rival lines.[2] That class of commodities is still transported by trains, the integrity of which is maintained, as far as practicable, at division-terminals. Their average rate of speed is over 15 miles an hour, and they are given preference on the road over trains loaded with bulk-freight.

The time-freight trains are a higher class of fast-freight trains, loaded with commodities of such a character as to require special facilities and care in transportation; or of such intrinsic value that delay in delivery

[1] Assuming that, on a certain ruling-grade, a train of 50 cars of 40 tons' gross weight, or of 2000 tons' gross weight and 1150 tons' net load, can be moved at a speed of 10 miles an hour by a locomotive with 36,000 pounds' tractive power, then, according to the rating on the Pennsylvania Railroad as per Appendix VII, Table XIV, the same locomotive would take a train of the same cars, fully loaded, over the same grade at a speed of 16 miles an hour, provided that the train weighed but 69 per cent. of 2000 tons, or 1380 tons gross and 805 tons net, in a train of 35 cars, each with 23 tons of net load. (See Appendix VII, Note IV.) If, on a division of 100 miles in length, this locomotive could haul 1150 tons net in 10 hours, at a speed of 10 miles an hour and 805 tons in 6.25 hours, at a speed of 16 miles an hour, then in 50 hours the total net tonnage hauled would be 5750 tons at 10 miles an hour, or 6440 tons at 16 miles an hour; which would be an increase of 12 per cent.

[2] See Chapter VI, p. 335.

counts up in interest on the investment in them; as for instance, silk or tea from the Orient through Pacific ports. These trains are run on schedules at rates of speed up to thirty-five miles an hour, passing through intermediate terminals unbroken. The cars with time-freight are identified by "symbols" composed of letters and numbers indicating their routeing and destination.[1] The symbols also serve to attract attention to cars so carded in case of accident or delay on the road. Time-freight trains are the especial care of train-dispatchers and, to further insure satisfactory service, special locomotives and train-crews are assigned to such trains. Perishables and live-stock are also given preferential service. Time-freight service is an important feature in British railway operation, as described in Chapter VI, pages 349, 350.[2]

Economy of Full Loads

The stress that is laid upon fully loaded trains by railroad managers is evinced in the Proceedings of the American Railway Association, in which it is stated that, in 1909, by increasing the average loading by one ton per car, the available equipment could be virtually increased by 69,457 cars, and an increase of one mile per car per day would mean 79,395 more cars, with daily average earnings for 200,000 cars.[3] The importance of fully loaded trains is so strongly impressed upon transportation officials that it is to be expected that the ambitious yardmaster will strive to keep his tonnage-reports up to the rating-sheet requirements and that, in consequence, there will be occasional reports of overloaded trains. In such cases the responsibility may rest with the Motive Power or the Rolling-stock Department rather than with the Transportation Department; but the dynamometer-test is the only standard by which this can be fairly determined.

Classification Yards, Freight and Passenger

As cars are concentrated at division or junction terminals, the marshaling of them promptly in trains, in such a way as to insure the economical

[1] See "Freight Terminals."

[2] As to live-stock, see Chapter V, Part II, p. 281, and "Freight Terminals," p. 184.

[3] On the Chicago, Burlington & Quincy Railroad, from 1900 to 1913, the average gross tonnage per train, in the principal locomotive-pool, was increased from 1200 to 3000 tons; and the average amount of car-mileage decreased from 84,000 to 48,000 miles. In 1900, twenty or more trains per day consumed, for 160 miles, an average of 7 hours at a speed of nearly 23 miles an hour. In 1915, the average time was 14 hours, with the rate of speed reduced nearly one-half, and the net load per train increased from an average of 250 tons to 600 tons.

In 1910, the Norfolk & Western Railway handled 6,722,495,887 ton-miles of freight with 10,578,541 revenue train-miles. In 1916, 12,131,187 revenue train-miles were required to move 11,795,891,557 ton-miles; being an increase of less than 15 per cent. in train-miles with an increase of 75 per cent. in ton-miles. The revenue train-load was increased from an average of 635 tons in 1910 to 957 tons in 1916, an increase of 50 per cent. in six years.

use of tractive power, is an operation that requires suitable yard-facilities, experienced yard-crews and intelligent supervision. It is almost impossible for trains to be made up in proper order, or with full tonnage, in a yard that is badly designed or with insufficient track-room. At such points, the traffic becomes congested, with consequent derangement which affects the operation of the entire line.

Some eight or ten years ago, on the Pennsylvania Railroad, it was found that the movement of traffic did not respond to the large expenditure that had been made to facilitate it. The speed of a car from Pittsburgh to New York averaged less than four miles an hour. It was standing still more hours than it was moving on the road. On another line, in three separate investigations, it appeared that from 81 to 84 per cent. of all the cars on the road were not in motion. On one of the largest roads in the country, the average time of all freight-cars in terminals on its line had been 18 hours, which was subsequently reduced to 13 hours. Five hours per day represents 5000 car-hours in a yard handling 1000 cars daily; which is equivalent to an addition of 213 cars in service, representing an investment of not less than $213,000.

The saving of time in a well-designed classification-yard is well worth the expenditure of millions of dollars. In a yard with tail-switching, a train of 60 cars was classified in 50 cuts in two hours, the switching-locomotive having in that time run 4.7 miles. In a "hump" yard, or summit-yard, the same work was accomplished in half an hour, with a total run of 1.14 miles. The yard at Gardensville, N. Y., on the New York Central Railroad, has track-room for 21,000 cars and 260 locomotives, with capacity for handling 10,000 cars daily.[1]

The opportunity for economy of labor in a great freight-terminal may be understood from the statement that in the Chicago Terminal District of the Chicago & North Western Railway the yard-organization includes 70 locomotives, 24 yardmasters, 40 switch-tenders, 80 yard-clerks and 700 yardmen. In order to secure economic efficiency in such an organization for the prevention of delays and of possible blockades, everything should be in readiness for instant action as soon as a switching-list is provided or information received of expected trains. For this purpose, a local telephone-system connected with the general yardmaster's office is of valuable assistance. The yard switches and signals should be kept in good condition, and day-and-night work will be greatly facilitated by eight-hour shifts. While switching is going on, the yardman at the head of a cut of cars should always be in view of the engineman. If he disappears from sight but for a moment, that should be considered as a signal to stop. By a strict observance of this rule, accidents from sudden collisions will be prevented.

[1] For construction and operation of classification-yards, see Chapter V, Part II, pp. 275–280.

The service in classification-yards is much simpler at points of origin than at important junction-points and at division-terminals, where trains with differing equipment and variously loaded are arriving at frequent intervals, and are to be rearranged for departure at successive hours for separate destinations. Locomotives and cabooses are to be detached, cars and brakes inspected, bad-order cars designated to be set out on repair-tracks, refrigerators to be re-iced, live-stock to be watered and fed, and explosives and inflammables to be carefully set apart.

This service is to be performed, in some instances, with 33 trains arriving in 24 hours and a maximum of seven in an hour, averaging 50 cars to a train.[1] As these trains are broken up, their component elements are to be distributed and rearranged in other trains for prompt departure. Systematic organization and intelligent supervision are necessary for this multifarious service to be efficiently rendered. Each and every car is to be identified by placards and checked on the way-bills, from which the tonnage is to be abstracted and totalized as the trains are made over and placed on the departure-tracks.

There is perhaps no more important factor in the efficient conduct of freight-train service than the proper make-up of trains. As a general rule, trains should be made up for points as far distant as practicable. Better dispatch will be given, even if cars be held up for 48 hours to make up a solid train, as they will thereby be kept out of intermediate yards, and extra handling will be prevented. The extent to which this general rule can be observed depends, however, upon prevailing conditions as to the specific character and total volume of the traffic, and also upon the physical features of the line and the relative importance of the business handled at the intermediate transfer points.[2]

Yard-service in connection with making up passenger-trains is a simpler matter, as the kind and number of the cars and their arrangement in a train are more uniformly dependent upon the character of the traffic for which the train is intended. The locomotive is to be suited to the train and to its scheduled speed; and not the train to the locomotive. Still, in large union-stations, the frequency of arrivals and departures, the necessity for handling cars between the station-tracks and the wash-tracks without interruption to the regular train-movements, and the incidental maneuvering of the train-equipment, call for careful attention to the requirements of the time-table and for skillful fulfillment of the demand for prompt and efficient service.[3]

Each train must be made up to suit the service for which it is intended; whether for suburban, excursion, local or through traffic; and as to mail, express, baggage, combination or smoking cars, or as to day-coaches or sleepers, or the special equipment for limited trains. Where racial dis-

[1] See Chapter V, Part II, p. 280. [2] See "Freight Terminals," p. 103.
[3] See Chapter V, Part II, p. 281; and also "Passenger Terminals," p. 241.

tinctions are observed, additional coaches must be provided. The number of coaches in a train must be varied to meet changing requirements. The wooden day-coach may seat 60 persons, the all-steel coaches seat 70, and a parlor car, 30. A Pullman sleeper with twelve sections can accommodate 50 persons, though usually not more than half of that number occupy the car. A train of eight cars in through-service will ordinarily consist of a mail, an express, a baggage and a smoking car, with three day-coaches seating 240 persons and a sleeping-car accommodating 50 at most; or a total of 290 passengers. A limited train of nine cars would be made up of a baggage-car, a buffet-car, an observation-car, a dining-car and five sleepers, of which four would be compartment-cars, with total accommodation for perhaps 200 passengers; though ordinarily not more than half-occupied.

On lines with terminals in large cities, the efficient conduct of the suburban service is of great importance. For persons with homes in the suburbs and business in the city, or "commuters," the arrangement of the time-table as to hours of arrival and departure, as to frequency of trains and as to the time consumed in the journey, profoundly affects their daily lives, and also the general character and the welfare of suburban communities. Commuters may be divided into three classes: those whose daily work takes them early into the city and who return late, those whose occupations admit of later hours in the morning and earlier in the afternoon; and the shoppers, whose frequent visits to the city conform to their domestic routine. By far the largest number of commuters constitutes the first class, who can spare no more time than from half to three-quarters of an hour for the journey each way; the second class can afford to take a full hour, and the third class even more.

Zones of Suburban Traffic

An examination of the local time-tables with heavy suburban traffic shows that the train-service may be separated in zones to suit these respective requirements. In the inner zone of 10 to 15 miles radius, the service is performed in 35 to 45 minutes by 20 to 30 trains daily each way, with many stops, and closely grouped between 6.00 and 8.00 A.M. and 5.00 to 7.00 P.M. In the middle zone of 15 to 25 miles radius, the service is performed by 10 to 15 trains within an hour, with as many stops but fewer of them within the inner zone. The service in the outer zone, 25 to 30 miles distant from the city, is performed in from an hour to an hour and a half, by trains in the later forenoon and earlier afternoon.[1] A few night-trains serve the three zones for the accommodation of late pleasure-seekers and the night-toilers. Where the trains are frequent and the trains are numerous, the stops are made at alternate stations. With electric traction, the number of stops is increased within the same

[1] See "Passenger Terminals," p. 324.

period of time, but its substitution for steam has not apparently had the effect of lengthening the radii and increasing the area of the several zones. The situation in the community-zones around London does not differ materially from that here described.[1]

Switching Service

Switching service is of three kinds:

1. Industrial and commercial switching, which is largely performed, either directly or indirectly, by the enterprises interested in the production or sale of the commodities handled;
2. Terminal service at union-stations, which is performed by the station-employees;
3. The distribution and making up of trains at the stations and in the classification-yards of the railroad companies by their own yard-crews, and which neither enters into the ton-mile computations nor into the freight-rates.

The magnitude of the switching-service of this latter character, as an essential element of transportation-efficiency, is indicated by the proportion of switching-mileage to freight-train mileage as follows:

Freight Train and Switching Mileage, 1914

MILLIONS OF MILES

Mileage	Eastern District	Southern District	Western District	United States
Freight trains	257	117	217	591
Switching	179	49	101	329
Proportion	70%	42%	47%	56%

[1] Suburban Service. London, October, 1907

Zone	Charing Cross, Miles	Area, Square Miles	Passengers		
			Number	Per Square Mile	Workman's Tickets
1	4–6	63	2,232,201	35,584	389,229
2	6–8	88	3,406,588	38,729	1,054,461
3	8–10	113	2,432,996	21,512	512,858
4	10–12	138	843,780	6,104	122,456
5	12–15	244	238,252	977	24,290
6	15–20	560	331,213	592	24,168
7	20–25	707	151,025	213	673
8	25–30	864	107,614	124	819
Total	4 to 30	2,777	9,743,669	3,509	2,128,954

"Passenger Terminals," pp. 274–275.

EQUIVALENT SWITCHING MILEAGE ESTIMATED AT SIX MILES AN HOUR

NUMBER OF LOCOMOTIVES				
Freight	17,053	5,923	14,429	37,405
Switching	4,926	1,422	3,533	9,881
Proportion	29%	28%	24%	27%
MILEAGE PER LOCOMOTIVE				
Freight	15,095	19,703	15,023	15,795
Switching	36,302	34,432	28,640	33,318

This statement is restricted to roads in Class I; that is, to those with annual operating-revenues in excess of $1,000,000; and is abstracted from a computation of transportation statistics for 1914 in Appendix VII, Table XVIII. In that year, the proportion of switching-mileage to freight-train mileage was 58 per cent. for the United States and 70 per cent. for the Eastern District. The proportion of switching-locomotives to freight-locomotives for the whole country was 27 per cent. and the average mileage per switcher was double that of the freight-locomotive. This is not actual performance in switching, but equivalent mileage, estimated at six miles an hour while so employed.[1] On this basis, and estimating the freight-locomotive mileage at 13 miles an hour between terminals, the freight-locomotives averaged 1215 hours per annum or 3.3 hours per day, while the switchers averaged 5533 hours per annum, or 15 hours per day. This statement emphasizes the comparative magnitude of the switching-service and the attention which should be given to it as an element of transportation-efficiency.

Switching-service is not only hindered by inadequate or badly designed trackage, but also by the lack of organization which results in crowding the freight-yards with cars that should either be on the road or in the shop. Systematic supervision is necessary to prevent such a condition from prevailing where hundreds, or even thousands, of cars are daily passing through a yard. For this purpose, it is essential that the yardmaster should know the condition of the yard. By means of a card-index, it is practicable for him to have in his office, at all times, complete information graphically displayed as to the number of cars passing through the yard, grouped as to hours of arrival and their destination, separated as to classes of freight and character of equipment. Where this plan has been introduced, there has been a reduction of 50 to 75 per cent. in the average time per car in the movement through the yard.[2]

[1] The actual distance covered in switching averages 2.31 miles for each hour's work in freight-service, and 2.78 miles in passenger-service. American Railway Association Proceedings. October, 1916, p. 125.

[2] See Proceedings of the Association of Transportation and Car Accounting Officers. No. 10, December, 1908, p. 1283, and No. 11, June, 1909, p. 1472.

Wrecking-train Organization

At each division-terminal and important junction-point, there should be provided a wrecking-train, consisting of a derrick-car, a tool-car, several flat cars and a passenger-car. The derrick-car should have the means for slow propulsion; the tool-car should be equipped with the appliances for replacing locomotives and cars on the track. An inventory should be kept with the car, which should be checked off after the car has been used, and missing or damaged articles replaced. One flat car should carry blocking, guy-poles, and a few rails and joint-fastenings; and another, a pair of standard freight-trucks. The passenger-car should have, at one end, a kitchen supplied with utensils and dry stores, to be occasionally renewed, and at the other, it should be fitted to provide first aid to the injured. It should also be equipped with a full set of signals, fuses, torpedoes, torches, gasoline lights and lamps ready for use, two field-telegraph instruments, climbing appliances, extra wire and a telephone-instrument; and should be fitted with insulated connections. An inventory should also be kept with this car.

The wrecking-crew should be drawn from the forces in the car-repair yard and should be composed of an experienced wreck-master, a competent crane-man and at least six of a repair-gang, together with a telegraph-operator and a line-man. The train should stand on a special track near the entrance to the yard in condition for immediate use. Each member of the crew, and the railroad surgeon, should report promptly at the train upon the sound of the prescribed signal. This is a matter to which more attention should be given than it generally receives. The maintenance of such a train, with an efficient crew, will greatly shorten the delay to the service from train-accidents, and be the means of saving life.

On lines exposed to obstruction by snowdrifts, a somewhat similar organization is required for winter use in connection with a snowplow. Where snow drifts into deep cuts, the plow with a rotary cutting-face greatly facilitates the work.

Empty-car Mileage

Empty-car mileage is a matter to be considered in a discussion of transportation-efficiency. The transportation-statistics for 1914, in Appendix VII, Table XVIII, show that a freight-movement of 1,843,000,000 tons was accomplished with 284,924,000,000 ton-miles and 13,507,000,000 car-miles, which is an average of about 21 tons per car. But this loaded movement was accompanied by 6,426,000,000 empty-car miles; that is, one empty car was moved for every two loaded cars. In consequence, the total car-mileage represented an average loading of 14.3 tons per car.

Empty mileage is unavoidable with a heavy mineral-traffic in cars which are unavailable for other purposes, but much of it is occasioned by efforts to return cars directly to proprietary roads by routes on which there is no return lading for them. The paying freight must not only be burdened with this expense, but also with the cost of the train-movements in motive power and for train-crews. In seasons of surplusage, it would seem practicable to prevent unnecessary car and train mileage by some provision for storing idle cars at unloading points.

The relative proportion of loaded and empty mileage in the Eastern and Southern traffic districts in 1914 was as 66 to 34, and in the Western District as 70 to 30. The variations below 60 per cent. and above 70 per cent. are given in Appendix VII, Table XIX. The lines with empty mileage in excess are those engaged principally in mineral-traffic, whose open top equipment is necessarily returned empty, except in the case of those with terminals on the Great Lakes that handle coal and ore in opposite directions. The lines with loaded mileage in excessive proportion are those whose principal traffic is in bulky commodities in lightly loaded cars.

Train Dispatching

When cars have been assembled in a train and placed on the departure-siding, the road-locomotive attached, the brakes tested, the train-crew having reported for duty, and the way-bills having been furnished to the conductor, the responsibility of the yardmaster is at an end and that of the train-dispatcher begins.

As train dispatching is now conducted, to the chief dispatcher is delegated much of the authority which was formerly exercised by the superintendent. He should be familiar with the controlling features of the line on his division; with the local peculiarities of the grades, curves and sidings, with the rating of the locomotives and their current condition, and with the respective capabilities of the principal yardmen, operators and trainmen. When the weather forecast seems to warrant such a precaution, the tonnage-rating should be judiciously reduced in order to prevent a blockade out on the line. In addition to having at hand all this information, and the aid of devices for promptly registering train-movements, the chief dispatcher must, furthermore, have a natural aptitude for immediate decision in giving train-orders under the confusing conditions that frequently exist on a busy division.

A dispatcher must provide for the occupation of the line by work-trains to the greatest possible extent, and yet be ready at any time to facilitate the passage of a high-speed train. Other emergencies arise, as when it becomes necessary to hasten assistance in case of a train-accident, or when from track-obstruction on a double-track line, the conflicting currents of traffic must be accommodated on a single track, or perhaps trains from a neighboring road must be suddenly detoured over his division because of similar obstacles. He must be careful in giving orders not to "bunch" trains at passing-points where the siding-accommodation is insufficient to avoid obstruction upon the running-tracks. Precedence is to be given to trains requiring dispatch, as fast-freight or time-freight or perishables or live-stock. Such trains should be brought into terminals ahead of slow freight-trains, in order to insure promptness in getting them out of the yard again, even if it be found necessary to hold other trains out on the road. Yet, in so doing, care should be taken not to have the trains follow each other so closely into the yard that they can not be speedily cleared from the running-tracks. Success in these respects depends upon the dispatcher's familiarity with the capacity of the terminals for the disposition of arriving and departing trains, and necessitates intelligent team-work by the dispatcher and the yardmaster. For men who are fitted to cope successfully with such conditions, there is a broad field of usefulness in railway operation.

Time-tables and Train Sheets

The first railroads were, for the most part, so short that the same passenger-train could cover the line daily, going and returning. Its time of departure from each station was printed on one side, and a few simple rules on the other side, of a bit of card-board; whence the term of "time-card" has been retained in the railroad vocabulary. On longer lines, the passenger-service was performed by one train a day, each way, leaving each terminal at a convenient hour in the morning. If either train failed to make the schedule meeting-point on time, the other train waited for it from fifteen to twenty minutes and then proceeded cautiously, flagging the curves. So long as it kept within the prescribed time of its schedule, it retained the right of way; but if it were unable to do so, then the opposing train could proceed, also flagging curves, until the trains met. Between the stations, there was a "half-way post," and the train that first passed that post thereby secured preference and backed the other train to a siding; and "running for half-way" was of frequent occurrence.[1]

A daily freight train, leaving each terminal in the morning, ran leisurely over the road, avoiding the schedule passenger-trains and waiting for them indefinitely if they were delayed. This train delivered and loaded the small lots of freight at the way-stations and set off or took on the loaded cars. In the lumber-regions, the saw-mills were placed along the line wherever the situation was most convenient to the forest-timber, and the sawed lumber was loaded upon special trains while they occupied the main line. This was, in fact, the method of train-service on many of

[1] Prior to 1845, on the Eastern Railroad of Massachusetts, in case a train was over one hour late in arriving at either Lynn or Salem, "The depot-master will immediately start on horseback to learn the cause of the delay." Trains began to be numbered on this road about 1848, each train retaining its number for the round trip. In 1855, the outward trains had the low numbers and the inward trains the high numbers. In 1872, outward trains bore the odd and inward trains the even numbers. There were no Sunday trains until 1874, nor uniformed employees until 1881. "The Eastern Railroad," F. B. C. Bradlee, Salem, 1917.

the early railroads in sparsely settled regions, and until the mineral-traffic became of importance.

In the more populous districts, and more especially in the New England states and along the North Atlantic seaboard, the train-service was more frequent. The station-sidings were not so far apart, and running for half-way was not customary. It was only on the longer lines with through-connections that there was a night passenger-service, usually with a single train from each terminal and, with heavier freight-traffic, there was a clearer track at night for the through-freight trains.

With an increasing number of passenger-trains, it became necessary to keep the freight-trains also on schedule, and the time-card was superseded by the more extended time-table. The increased number of passing-points made the construction of the time-tables quite a serious matter and, when a change became necessary, the superintendent would retire into seclusion, with his clerk, until the schedules of the opposing trains had been so fitted into each other as to insure correctness with respect to the passing-points. On a road over a hundred miles in length, and with comparatively frequent train service, when a new time-table went into effect, all those concerned were somewhat anxious until all trains had been satisfactorily accounted for. On some roads the same schedule was kept in effect for years. In one instance of this kind, when it became necessary to change the time of a train a few minutes, this was accomplished by moving the time of all the trains around just that number of minutes.

The time-table of a prosperous and progressive railroad grows with its growth, and with cumulative experience as to changes in social requirements and the character of its traffic. The time-table is also affected by improvements in alignment and equipment, and by the establishment of additional junction-points. This is especially true of single-track operation, as increasing traffic develops additional meeting-points to avoid congestion. The time-table usually includes a supplement containing information as to the location of sidings, water-stations, grade-crossings and drawbridges. A speed-schedule, to indicate the time elapsing for different distances at different rates of speed, is of use in running a delayed train to make a meeting-point. It is advisable to equip with speed-indicators the locomotives assigned to high-speed trains with long runs between stops. The time-table may also state the time usually allowed for stops.[1]

[1] ALLOWANCE FOR TRAIN STOPS

	REGULAR STATIONS	FLAG STATIONS
To change locomotives	5 minutes	
Train of 7 cars	2 minutes	1 minute
Train of 8–9 cars	3 minutes	1½ minutes
Train of 10 cars	4 minutes	2 minutes
Train of 11–12 cars	5 minutes	2½ minutes

The construction of time-tables was greatly simplified by the use of the graphic train-sheet, which was introduced in the fifties by superintendents who had had the training of a civil engineer, using profile-paper for the purpose. This made the arrangement of passing-points a matter of certainty, in advance of the actual change of time. The number of passing-points increases rapidly with the addition of trains.[1]

The increasing complexity with heavy traffic on a single-track line is seen by a comparison of train-sheets taken from actual practice on the same division, eighteen years apart (Appendix VII, Plates I and II), showing that single-track operation had reached the limit at which it becomes necessary to obtain relief by the construction of sections of second-track.

The daily collocation of the passenger-trains on a system covering thousands of miles of main lines and branches, in such form as to keep the chief transportation-official promptly advised of the manner in which the service is being performed, and of the causes and location of delays, is an important feature of transportation-efficiency. On the Southern Railway the information for this object covers a region extending from the Potomac to the Mississippi River, and from the Ohio River to the Gulf of Mexico, with continuous through-train service from Washington of 792 miles to Jacksonville, Fla., and of 926 miles to Memphis, Tenn. The causes of delay are classified under appropriate headings, such as waiting for foreign connections, delays caused by freight-trains, meeting trains, derailments, locomotive-failures, mechanical causes, slow-orders, blocks, mail transfers and miscellaneous. These daily statements are abstracted monthly, showing the percentage of trains late and average loss of time. The several divisions are classified on this basis, as the "Blue Ribbon" class, without delays; the "Red Ribbon" class, with delays of less than 15 per cent.; and the "Yellow Ribbon" class, with a greater percentage of delays.[2]

[1] See diagram in Appendix VII, Table XXV.

Possible number of passing-points on single-track, in a distance of 120 miles, as calculated by P. M. La Bach, speed of passenger-trains, 30 miles an hour, and of freight-trains, 15 miles an hour, shown in the following table:

Trains per Day

Passenger	Freight	Passing Points
1	1	6
2	2	20
3	3	36
4	4	71

[2] Passenger Train Performance. Southern Railway. May, 1915.

Trains run	13,803
Trains losing time	1,271
Total delays	929 hours, 9 minutes
Average delay to late trains	43 minutes

With the extension of our railway system and the accompanying ramifications of passenger-train connections, the changes of time-tables to facilitate through-service began to be made at meetings of neighboring transportation-officials. It was then found convenient to concentrate the dates of such changes by the organization of the General Time Convention, covering the states north of the Potomac and Ohio rivers, and of the Southern Time Convention in the more southern states. At these conventions, the schedules for through passenger-train service were agreed upon in general outline. The time of arrival and departure at connecting terminals had to be carefully adjusted, by reason of the frequent differences in the local standards of time. This situation was intensified by the wide differences of time at the junctions or intersections of long lines of road, using the local standards of terminals hundreds of miles apart as to longitude. For instance, on one line extending for about four hundred miles in an east-and-west direction, there were ten standards of local time to be considered. In its published time-tables, at some junctions and terminals, its trains were timed to arrive after connecting trains had apparently left, although there was actually an interval of twenty minutes; and it exercised trackage-rights over six miles of another line, where a difference existed of several minutes. On one line between New York and Boston, there were three standards of time with a total difference of twelve minutes.

Standard Time

The discordance of railway standards of time occasioned so great inconvenience to the traveling public that it had attracted the attention of horologists. Greenwich Observatory time had been established as a standard for the British Islands on January 13, 1848, by Act of Parliament. In 1869, Professor Charles F. Dowd of Saratoga, N. Y., proposed that railway-time in the United States should be standardized by plus or minus signs from meridians one hour apart, based originally upon the meridian of Washington, but afterward on that of Greenwich. Between 1876 and 1882, Sir Sanford Fleming, Chief Engineer of the Canadian Pacific Railway, advocated a similar plan, complicated with a twenty-four hour system and the substitution of letters for the hours, instead of numbers. Suggestions of this character were also made by Professor Benjamin Pierce and by Dr. Thomas Hill, President of Harvard University. None of these proposals were approved by railroad-officials, as the establishment of standards arbitrarily based upon meridians cut across so many lines as to render such a system impracticable.

In 1881 Dr. F. A. P. Barnard, with Professor Cleveland Abbe and Professor Ormond Stone, presented the subject to the General Time Convention, by which it was referred for a report to its Secretary, Mr. W. F. Allen. At that time, there were over fifty standards of time in use on our railway system. As manager of the Official Railway Guide, Mr. Allen was familiar with the difficulties to be overcome in any solution of the problem that would be acceptable to railroad-officials. In April, 1883, Mr. Allen presented a report including certain propositions as follows:

1. The division of time over the earth's surface is to be based upon the meridian of Greenwich Observatory and upon each successive fifteenth meridian around the globe. The whole 360 degrees of its circumference would thereby be divided by meridians one hour apart; and in sections 7½ degrees on each side of these meridians, the time on that meridian would be the standard.

2. The boundaries between each section are to be so modified as to avoid cutting arbitrarily across the operation of east-and-west lines, thus meeting the most important practical objections to the establishment of the change of time by even hours at such boundaries.

The General Time Convention gave its approval to this plan and authorized its Secretary to secure agreements for its adoption. At a joint meeting, in October, 1883, of the General Time Convention and the Southern Time Convention, Mr. Allen reported that he had secured agreements to put the plan in use from the managements of 75,000 miles of railway and had been assured of the coöperation of the Naval Observatory at Washington, of the Cambridge Observatory and of several municipal governments. Both conventions then resolved to put Standard Time into effect on Sunday, November 18, 1883, when over fifty standards of time were merged into five on the railroads in the United States and Canada.[1]

The practical effect of the adoption of Standard Time has been to unify train-movements in this respect, in sections, as follows:

1. Intercolonial Time, based on the 50th meridian, applies only in New Brunswick and in Nova Scotia.

2. Eastern Time, based on the 75th meridian, is in use in virtually all of the Atlantic Coast states down into Georgia, and includes West Virginia. It extends in Canada to the meridian of Fort William on Lake Superior.

3. Central Time, based on the 90th meridian, prevails in the states in the Mississippi Valley, along the Great Lakes and the Gulf of Mexico, including Florida and the greater part of Georgia. It extends westward into the Prairie states and, in Canada, to the eastern border of Manitoba.

4. Mountain Time, based on the 105th Meridian, extends thence westward to the states on the Pacific Coast.

5. Pacific Time, based on the 120th meridian, governs train movements in the Pacific Coast states and in British Columbia.

Virtually, four standards of time cover the railway system of the United States.

At 11.55 A.M., 75th meridian, business ceases on the telegraph-lines

[1] "Short History of Standard Time and its Adoption in North America," published privately by W. F. Allen. November, 1903.

throughout the country. The master-clock in the Naval Observatory at Washington then commences to beat seconds over the lines, skipping one second before each half-minute and five seconds before each minute, until 11.59 and fifty seconds. The circuit then remains open for ten seconds. When it closes again, it is exactly Noon, Eastern Time; and all clocks and watches are regulated accordingly. At many of the principal stations, the clocks are synchronized electrically with the transmission of time from Washington. Every railroad company requires its train and station employees to have their timepieces regulated periodically by its official watch-inspectors, within a variation of thirty seconds a week.

Since the establishment of Standard Time in America, its use has been extended all over Europe, except in Ireland and Portugal; also in the greater part of South America, in Egypt and South Africa, in Australia, Japan, the Philippine Islands and in Porto Rico. The loss in time in a westerly direction and the gain in an easterly direction from Greenwich Observatory, in circumnavigating the globe, are neutralized in the Pacific Ocean, in crossing the 180th meridian, by dropping a date one day when going eastward, and by keeping the same date for two days when going westward. Over the larger part of the earth's surface, clocks are now regulated by Standard Time. While the hours may differ, according to the controlling meridian, the minute-hand points contemporaneously to the same mark on the dial, around the world. A traveler can cross the ocean from New York, and feel assured on arriving at Naples, for instance, of the interval of time available for taking the train for Rome, by looking at the minute hand on his watch. Though the hour-hand must be adjusted for the proper meridian, the minute-hand remains unaltered.

Yet the advantages of a uniform standard of time were so little appreciated by the general public in the United States that its adoption by the railroad companies met with strenuous opposition in communities whose local time differed materially from the railroad standard. Even to this day, the system has been legally established in but four states of the Union. The system of numbering the hours from one to twenty-four, which has long been in use in Italy, has not been generally sanctioned, although it was advocated in Canada by Sir Sanford Fleming.

Uniform Train Rules

Joint-action in the adoption of Standard Time, and the change on the southern roads from the five-foot gauge to the standard gauge, brought about a merger of the Southern Time Convention with the General Time Convention.[1] This step afforded the opportunity for harmonizing another

[1] The General Time Convention was organized in April, 1875, with 36 delegates representing 24 roads north of the Potomac and Ohio and east of the Mississippi River. The Southern Time Convention was organized in October, 1877, covering the lines southward of the Potomac and Ohio rivers. The two conventions

feature of railway operation by the adoption of a code of uniform train-rules. Differences in the details of train-service were many, and often widely divergent, even upon neighboring roads. Rules were variously interpreted, though verbally alike; nor were there any common forms of train-orders. A dispatcher might issue orders in language at times so indefinite or obscure as to lead to their misinterpretation. Hand, lamp and whistle signals not only differed, but even conflicted, on tracks and at stations used jointly by separate managements. The difficulty in reconciling local prejudices could only be appreciated by those who took part in the protracted deliberations by which uniformity was attained in the Code of Standard Train Rules, adopted in 1899.

The Code, which had originally been prepared only for single-track operation, was supplemented by other rules for train-movements in double-track operation and on three or more tracks.[1] Signals of every character are illustrated and their specific indications clearly prescribed. The phraseology of rule and train orders is carefully expressed to meet each preconceived situation in train-movements, and the extent of the authority or responsibility of every official and employee concerned in them, from the train-dispatcher to the brakeman, is definitely determined.

Since the adoption of the Standard Train Rules, they have had the test of nearly thirty years in practical use. During that period, the Standing Committee on Train Rules has been repeatedly called on to interpret their application under every condition that the ingenuity of dispatchers, trainmasters or trainmen could suggest. From time to time, the rules have been amended to conform to changes in operating-conditions, but always by experienced transportation-officials, who have exercised due discretion in modifying the action of their predecessors. The value of their work has been so generally recognized that a trainman from a New England road can go to the Pacific Coast with entire confidence in his acquaintance with the manner in which the service is conducted there.

As the Standard Code is in force to-day, it is contained in 147 octavo pages, covering also the automatic block system, and including interlocking rules. Its use has benefited every train-employee in the country, and has been so greatly instrumental in increasing the safety of train-movements that, in the public interest, the Interstate Commerce Commission might well recommend legislation to make its adoption obligatory throughout the United States.

were consolidated as The General Time Convention, in April, 1886, with a change of title in April, 1891, to The American Railway Association. — "Railway Operation Associations." W. F. Allen. January 11, 1909.

[1] In England, the left-hand track is the running track, following the custom there on public highways. In other countries, for the same reason, the right-hand track is used. It was stated in 1910 that, on the Lake Shore & Michigan Southern Railroad, the change had been made to the right-hand track at a cost of over a million dollars.

TRAIN RIGHTS AND TELEGRAPHIC DISPATCHING. TRAIN STAFF

At first, the control of train-movements was directed to establishing a scheduled interval of time between them. But this interval was liable to derangement by unforeseen circumstances, and could only be restored by the action of the train-crews themselves. The next step taken in the resumption of external control was the display of signals at fixed points, beyond which a following train was not permitted to pass until a certain period of time had elapsed from the departure of the preceding train; but this plan did not secure a preservation of the time-interval if the preceding train were delayed between stations; nor did it provide for the meeting of opposed trains, if either were delayed.

In the latter case, the only provision for absolute safety lay in holding all trains moving in one direction until expected trains from the opposing direction had arrived. To prevent the consequent congestion of traffic, trains in one direction were given the right to proceed from a meeting-point, after an allowance of time for the possible difference of watches. This plan was, however, ineffective when a train with the right of way was itself unable to proceed. In this emergency, after a certain lapse of time, the precedence passed to the opposing train, so long as it could maintain its schedule. When this could no longer be done, the control of train movements reverted to the respective train-crews, and anarchy prevailed until the time-table could be reëstablished.

The field for train-control was greatly enlarged with the introduction of the electric telegraph system which had been considerably extended in the United States before its value in railway operation was generally recognized. Although built along the right-of-way, wherever this was permitted, its offices were opened only in towns whose commercial relations afforded them profitable business, and they were usually remote from the railroad stations. The earliest use of the telegraph, as an adjunct to train-movements, is said to have been due to an emergency on the Erie Railroad in 1851, when Charles Minot, the superintendent, held a delayed train by telegraphic order to give the right of road to the train on which he was a passenger. He afterward framed rules for controlling train movements by telegraph.[1] The establishment of telegraph-offices at railroad stations was subsequently made a condition for the use of the right-of-way for telegraph lines.

Train-orders were at first only issued over the signature of the superintendent, and the independent authority of the train-dispatcher over train-service was not customary until about 1870. This innovation was not generally favored by transportation-officials of the elder generation. In 1856, on account of a misunderstanding of orders, a freight-train on the Eastern Railroad of Massachusetts waited all night at Salem for an extra

[1] "When Railroads Were New," p. 104.

passenger-train, which also passed the night at Ipswich, 11 miles away. Yet there were public telegraph offices in the railroad stations at Boston and Salem. In an investigation of the Revere disaster, which occurred on this road in 1871, in reply to a suggestion that the accident might have been prevented by the use of the telegraph, the Superintendent, who had been in office since 1855, said that he "could not be responsible for the operation of a road running the number of trains he had charge of in reliance on any such system." At that time, there were 66 trains daily with numerous extras, on 218 miles of line, with but 18 miles of second-track.[1]

Train-dispatching, or the control of train-service by telegraphic orders, was developed in the United States in single-track operation upon the roads with terminals in Chicago, and was introduced into the East about 1872. Originally resorted to only in emergencies, it has now become the rule to move trains by telegraph. Fundamentally, train-dispatching is the temporary rearrangement of meeting and passing points by special orders, to facilitate the movement of delayed trains. Its function in this respect, however, has been extended to the control of the entire train-service as regulated by the time-table, by the introduction of trains running under special orders or in sections of a scheduled train. On one important road, there are but two scheduled freight-trains daily out of its terminals, one in the morning and the other at night; all other freight-trains are run as sections of these trains.

Efficiency in train-dispatching requires the sole use of telegraph-wires, with day-and-night offices at all passing-sidings and junctions. In recent years, the telephone has been coming into use; first, as an adjunct, for transmitting telegraph-orders from telegraph-stations to outlying sidings and classification-yards; and later, as a substitute for the telegraph. By repetition in return, equal accuracy is insured and with greater promptness. The initial cost is somewhat greater, but the cost of maintenance is about the same.[2] At the beginning of 1912, the telephone was in use for this purpose on nearly 59,000 miles of line. In 1914, there were 26,241 telephones and 33,396 telegraph instruments in connection with the manually-controlled block system. On several roads, trains are provided with a portable apparatus which can be readily connected with the telephone-wire. It is also supplied to bridge and rail-laying gangs, to track-supervisors and work-trains, and to superintendents' cars. Wireless communication with moving trains has been experimentally tested on the Delaware, Lackawanna & Western Railroad.

In single-track operation on British railways, the precedence in train movements was secured between signal-stations by the use of the train

[1] "The Eastern Railroad."

[2] The telephone (invented in 1876) was first regularly used for train-dispatching in 1882 by E. H. Whorf, superintendent of the Boston, Revere Beach & Lynn Railroad. His successor, C. A. Hammond (1883–1893), greatly improved the system, adding several features for securing accuracy and responsibility.

staff in the hands of one train-crew. Until that emblem had been delivered to a station-master, no other train could enter the occupied section. Under this mode of operation, train-movements necessarily alternated in direction. No train could move without the staff and, if there were any considerable delay in returning it by train, there was a consequent congestion of trains at the other end of the section, which could only be relieved by sending the staff back by a messenger on horseback. When this condition could be foreseen, it was provided for by running trains in a group, with a time-interval between them. Each successive train was furnished by the station-master with written authority to proceed until the last of the group bearing the train-staff had delivered it at the end of the section, which was thereby freed for the passage of opposing trains.

A train-staff system operated electrically has been devised by the General Electric Company, by which the staff-instruments at the ends of a section are connected and synchronized, so that the withdrawal of a staff can only be effected by the joint-action of the two signalmen. The staff is a metal rod, six inches long. Half of its length serves as a handle; the other end is turned down to rings of different diameters to actuate the locks of the staff-instruments. But one staff can be taken out at a time, though they can be inserted at either end without the coöperation of the other operator. Each instrument may be equipped with from twenty to thirty staffs in grooves from which the upper one must be removed first. A special form of staff-and-tablet apparatus enables a train carrying the staff to be placed clear of the line at an intermediate point, and to restore the instruments at the ends of the section to their normal position. The staff is virtually a key to the block, as it unlocks the signals controlling the entrance to it, and also to any intermediate switch. It can be caught by hand on a train passing at a speed of fifteen to twenty miles an hour.

Train-dispatching, in the American sense, has never found favor in British railway operation, nor on the Continent, where British methods prevail.

The Block System

On account of the density of the traffic which had previously existed, many of the English lines were originally of double-track construction, and the short distances between the stations facilitated the control of trains by fixed signals. As early as 1851, electric call-bells for this purpose had been placed at the stations. As the use of fixed signals became more general, the adoption of telegraphic communication was accompanied by the development of a different method of control by establishing definite intervals of space between trains, instead of a time-interval. In 1854, a block system with visual signals was introduced upon the London & North Western Railway. Manually-controlled signals then came into general use. In 1876, the Metropolitan Railway in London was operated under a block system with 3½-minute intervals.

Under the block system, each section between telegraph stations is termed a "block" and into this section no train is permitted to enter until, by communication between these stations, it is known to both that the block is unoccupied by another train. Under the train-dispatching system, train-orders are directed to the conductor of a train. Under the block system, the visual indications controlling the movement of an approaching train are communicated to its engine-driver.

At first, the entrance-signals merely indicated that there was or was not a train in the block. If the block was occupied, an approaching train could not pass the signal until it indicated that the block had been cleared. But, just as increasing traffic had become congested by a strict observance of the time-interval between stations, so did the same experience follow the institution of the space-interval, and the rule was therefore so modified as to permit a following train to enter a block with the knowledge that it was occupied. This is the broad distinction between the absolute and the permissive block system.

In the United States, the necessity for more direct and immediate control of train-movements was provided for by supplementing telegraphic train-orders with fixed signals. Such a system was put in effect, in 1884, on the Pennsylvania Railroad between New York and Philadelphia. Manually-controlled signals were introduced on the New York Central & Hudson River Railroad in 1882; but the first important use of these signals in America in single-track operation was in 1884 on the Canadian Pacific Railway.

The principle of the block system has been extended to a diversified control of train-movements by increasing the number of indications that give information to an approaching train. For this purpose, visual signals may vary in color, form or position. By common consent, red indicates danger and is a signal to stop, whether displayed from a station-master's office or from a signal-cabin, by a track-gang or by a casual wayfarer.[1] The signal may be a disk, or (usually) a semaphore-arm. Formerly, a ball or light at a masthead was sometimes used to give right-of-way at drawbridges or railroad crossings.

As at first used, the "two-position semaphore," with its arm or "blade" extended to the right of the signal-post next to the running-track, showed two indications only. When horizontal, it indicated danger, "stop." When inclined downward it indicated safety, "proceed." Placed at the entrance of a block it gave the stop-indication if the block was occupied, or the proceed-indication if the block was clear. Since the speed and momen-

[1] The white light, as an indication of safety, was superseded by a green light on the Great Northern Railway in England in 1876; and by a yellow or amber-colored light on the Pennsylvania Railroad, June 28, 1909.

tum of trains have been increased beyond the ability to stop them within the distance at which, under all circumstances, the signal can be seen by an approaching train, it became necessary to place a supplementary signal nearer to the coming train, and at a sufficient distance in advance to permit of a safe stop before the signal at the block-entrance—called the "home" signal — should be reached. The home signal was distinguished by having a square-ended blade, while the advance, or "distant" signal had a notched end like a fish-tail.[1]

The distant signal simply repeated the position of the home signal, thus giving advance notice of that signal's indication. Afterward the two signals were placed on the same post at the entrance of each block, the square-ended arm placed above the notch-ended arm. Both arms horizontal, indicate that the block immediately ahead is occupied; both arms inclined downward, that two blocks ahead are clear; and the upper arm inclined and the lower horizontal, that only one block ahead is clear, and trains must proceed with caution expecting to find the second block occupied. Each arm is counterweighted, to bring it to the horizontal position, in case of a broken connection.

A further improvement consisted in using the "upper quadrant" for the safety or "clear" indication; the upper inclined arm showing more distinctly, and avoiding the need of counterweighting and the liability of the arm being frozen in the clear or "proceed" position.[2] The single-arm "three-position" semaphore thus combines the functions of the home and distant signal. Its position is horizontal when the first block ahead is occupied; inclined 45° above horizontal when only the first block is clear; and pointed vertically upward when both the first and second blocks ahead are clear.[3]

The general arrangement of a set of signals, as to color, form and position, is termed its "aspect," — the impression, as a whole, which it makes upon the vision of the engineer of an approaching train. The aspect may permit him to enter an occupied block, or may indicate that the next signal is at "stop," or that a train-order is to be given to him, or that his speed is to be restricted through an interlocked route, or that a drawbridge is open. Three or more signals may be located in the space of a few hundred feet; all to be read while approaching them, perhaps at high speed. It is a question whether this use of signal-apparatus for other purposes than simply to preserve a space-interval between trains is not being overdone, and whether, in the interest of safe operation, the aspect should not be confined to two meanings only — "stop," or "proceed."

The length of a block section varies with the frequency of train-move-

[1] The fish-tail notch was introduced on English railways in 1872, and was made obligatory in 1877.

[2] This change was introduced into the United States in 1906, and is now in general use.

[3] For standard signal indications, see Appendix VII, Note VII.

ments. On the New York Central Railroad, there are 225 block towers between New York and Buffalo, a distance of 440 miles. On the Pennsylvania Railroad between New York and Philadelphia, the block sections are in no case more than 4000 feet in length, with an allowance of two minutes between trains. In the New York Subway, more than 2000 trains start from the terminals daily and, in the "rush hours," trains follow each other at intervals of one minute and forty-eight seconds. The block sections at the stations are shorter than the length of the platforms, which accommodate ten-car trains.

Automatic Block System

Under the manual system, the information that the block is or is not occupied is conveyed to the engineer of an approaching train through human agency, and the possibility of error is tripled by the intervention of two other persons. The engineer may either misinterpret or disregard the signal indications; the receiving operator may misinterpret or disregard the information which is to control the display of signals; the sending operator may either transmit that information incorrectly or not send it at all. In these respects, the manually controlled block system was originally defective.

The effort to eliminate human fallibility began with the control, at the entrance-signal, of the action of the operator at that point when it should be necessary to inform an approaching train that the block was or was not occupied. By placing the appliances for that purpose under the control of another operator at the outlet of the block by means of an electric circuit, the receiving operator at the block entrance could not display a signal improperly, and there was one mind the less to make a mistake. At the outlet of the block, it was required to guard against the transmission of incorrect information and of failure to send information at all. The latter contingency is not so important where the position of the entrance signal can be changed only by the act of the sending operator, but protection against incorrect transmission is more difficult to secure.

The operator at the outlet determines the condition of the block, first from a notification that a train has entered, next by actual observation of its passage. It is not sufficient for him to know that a locomotive has passed out, but also that every car which was attached to it when it entered had passed out with it. If this operator knows that the block is clear, then the assurance should be returned to him that this information has been correctly transmitted and that the entrance-signal is in proper position. When rules and appliances have successfully brought the system to this stage, the next step is to eliminate the operator at the outlet of the block.

This object has been attained under the automatic block system, which had its origin in the United States with the invention of Hall's automatic disk-signal. This signal was experimentally tested on the Eastern Railroad in Massachusetts, when train dispatching was introduced there in 1872. It was, however, only made applicable as an accessory to the block system by its association with William Robinson's electric closed track-circuit in 1879, on the Fitchburg Railroad. Automatic apparatus was afterward applied to semaphore signals, but this date may be fixed as the era of double-track operation under the block system, as distinguished from signal-track operation by telegraphic orders. Electro-pneumatic signals were introduced in 1885, but the first extensive automatic-signal block system was installed in 1891 on the Cincinnati, New Orleans & Texas Pacific Railway. The next installation was on the Chicago & Alton Railroad in 1879. In 1915, this system was in general use on 4466 miles of line on the Southern Pacific and Union Pacific railways. Notwithstanding its advantages, automatic signaling has not been generally adopted on steam-operated roads. The manually-controlled system is usually preferred in Europe. In the United States, in 1914, out of 86,738 miles of track under block signals, 52,032 miles were under some one of the non-automatic systems.[1]

Under the automatic system, devices actuated by the train, as it passes the entrance and the outlet of the block, simultaneously operate a display of the signals in the positions required to block the interval of space into which the train is entering, and to clear that which it is leaving. This effect can also be extended to the entrance of the block next behind it, so that the engineer of a following train may thereby be informed in advance, not only as to the condition of the block ahead of him, but also as to the block ahead of that. By the use of a closed track-circuit, the entrance or home signal can not give the indication that a block is clear, so long as a single pair of wheels is in the running-track within the block, or while any intervening switch is misplaced.

The characteristic features of the automatic block system are continuous insulated track-circuit and the operation of the signals at the ends of the blocks by electric mechanism which holds them in the clear position. As soon as the front wheels of a train enter the block, the electric current is short-circuited through the wheels and axles. The signal, being deprived of electrical energy, falls by gravity into the horizontal position, indicating that the block is occupied, and so remains until the last pair of wheels has left the insulated rails. The electrical energy then restores the signal to the position indicating that the block is unoccupied. The opening of a switch or the breaking of a rail, by interrupting the continuity of the current, likewise releases the signal from the clear position.

Electric Signaling

Electric traction requires the uninterrupted use of the rails in the running-track; therefore it becomes difficult to divide the track into insulated

[1] The development of the several methods of operating fixed signals is described in Chapter V, Part II, pp. 257–260.

sections for block signaling. On electric lines operated by direct current, it was necessary to employ alternating current for the signal track-circuit. For this purpose, "inductive" or "impedance" bonds are substituted for the insulated joints on steam-operated roads. The alternating-current signal track-circuit was first developed satisfactorily in 1902. But for its use in connection with the inductive bond, it would not have been practicable to operate either the Grand Central Station or the Pennsylvania Railroad Station in New York City.

Upon the Chicago, Milwaukee & St. Paul Railway, the electrified section of 440 miles over the Continental Divide is operated under colored signals only, in place of the semaphore. There are eight signals between sidings that are at an average distance of about seven miles apart. The circuits are arranged for single-track operation under permissive three-light signals; red, for stop; green, cautionary; white, proceed. A pilot-lamp gives the indications, if the main lamp should burn out. A small red marker-lamp below the number-plate, staggered as to the main lens, locates the signal at night if the indication should not be displayed. The range of the signal-lights in the daytime is 3000 feet under normal conditions, and 2000 feet under the most unfavorable conditions, with the sun shining directly on the lens. On curves, the lens is provided with deflecting prisms, which give the beam of light a wide spread. The indications can be seen during a driving snowstorm in the daytime much farther than it is possible to see a semaphore blade.[1]

Automatic Stop

A further step has been taken for the protection of trains against the neglect or misinterpretation of signals by enginemen, by the introduction of appliances connected with block signals which shall strike the cab-gong, or sound the whistle, or apply the brakes, or even close the throttle-valve of an approaching locomotive, before it passes within an occupied block. Such appliances are in use on several electric railways, where the trains are light and of the same character. But the application of automatic control to the general train-service of a steam-operated road involves many serious considerations, as will be seen by reference to the requisites for such an installation as prescribed by the American Railway Association.[2] An automatic stop in connection with an electrically-operated block system has been in use for some years on 107 miles of double-track on the Chicago & Eastern Illinois Railroad, which acts upon the air-valve of the locomotive. It also closes the throttle-valve on locomotives attached to passenger-trains, but not on those upon freight-trains. The permissive block-system, which is of great value on lines with heavy traffic, is inadmissible in connection with an automatic control.

The primary difficulty in the correlation of train-movements directly

[1] Railway Age Gazette, September 8, 1916.

[2] See Chapter VI, p. 309.

with the signal-indications of the block system is due to the operation of trains by motive power of an entirely different character from that by which the signals are actuated, and which is derived from a source borne independently by the train. This difficulty does not exist in providing for the automatic control of train-movements in electric operation, where both the train-movements and the signal-indications are actuated by the same motive power and from a common source. A megaphone-horn connected with the stop-signal and actuated by a treadle beside the running-rail would sound an alarum, when operated by the wheels of a passing train, that would not only arouse a drowsy engineman but would also give a wide-spread notice whenever the stop-signal had been disregarded. The purpose of the automatic stop is to provide against the inattention of the engineman to the signals. As this purpose should be attained more simply by close supervision of the manner in which the signal-indications are respected, the introduction of automatic train-control would seem to be unnecessary.[1]

Interlocking Improvements

Proceeding on a line parallel with the development of the block system, there has been an introduction of appliances for greater security against open drawbridges or misplaced switches and at railroad crossings, in connection with interlocking apparatus controlling several of such points from one station. This control has been made interdependent with the control of the block signals by marvelously ingenious mechanism to prevent a route from being altered, unless the change can be safely made. The locking-bar, or "detector-bar," used to prevent a switch from being changed under a passing train, has been replaced in automatic signaling by specially designed relays operated by alternating current. "Approach-locking" is used on full-speed tracks by which a signal, having been accepted by a train, is locked until the train has passed. In Europe, the interlocking is still largely under manual control.[2]

The intervention of mechanical appliances in the movement and control of signals, switches, drawbridges and crossings, and the interlocking of such appliances, have induced the substitution of other motive power for muscular energy and, at the present time, electricity, compressed

[1] On the Pennsylvania Railroad, in the first six months of 1915, 2,000,000 efficiency tests showed 99.9 per cent. of correct observance of rules by 135,458 employees. There were 23,390 tests in the use of signals with 99.4 per cent. of correctness. Out of 10,000 tests with signals set at "stop," in only 13 cases did the train pass the signal by as much as one foot. Railway and Locomotive Engineering, September, 1915. See Appendix VI, Note II.

[2] The periscope has been utilized on the Northwestern Elevated Railroad in Chicago, placed on the top of a switch tower at a sharp curve where the view is obscured by buildings. The towerman is thus enabled to have a view of trains approaching from either direction.

air and other gases are employed in this operation, either singly or in combination.[1]

On the Pennsylvania Railroad, at Greensburg, Pa., an electro-pneumatic interlocking plant controls from a single cabin, 155 switch signals and other functions with but 48 levers, in a territory 2450 yards in length. The east home signal is 3700 yards distant from the west home signal one, and the distant signals are over 5000 yards apart. In the Pennsylvania Railroad station in New York City, the interlocking cabin at the west approach, spans five tracks and covers a machine which controls 124 signals, 30 double-slips and 47 switches. In one building at the Grand Central Station, the interlocking machines contain 400 levers on one level and 360 on the other, all actuated electrically; and the movement of the trains is shown by electric indicators.[2]

In important passenger-stations, electric communication between the gateman and the conductor of a departing train actuates light-signals that inform the gateman when the train is ready to receive passengers, and advise the conductor that the gate to his train has been closed. By similar means, the station-master can send the number of the outgoing train's track to the interlocking cabin from which the locomotive-engineer receives a signal that his routeing is fixed. From that moment, the route can not be changed until it has been cleared by the train.

At a converging junction where trains may approach at nearly the same moment, it becomes necessary to give one of them precedence. With heavy freight-trains or on a descending gradient, this order of preference once established should never be changed, and one of the trains should be held at the previous signal. With lighter trains on an ascending gradient, the service may sometimes be expedited by changing the precedence as the trains approach. Where the junction arrangements are automatically controlled by the track-circuit, this can not be done under ordinary conditions though it may be accomplished by the use of time-relays.

In each converging track there is a length of insulated track-circuit in connection with a relay controlled from the signal-cabin. This relay is set so as to require for its operation more time than would be consumed by a train passing over the insulated track at a greater speed than 1½ miles an hour, which is equivalent to a train slowing down for a stop. At any higher speed, the locking is automatically released, and the clear signal may be changed from the other track.

This arrangement is however inoperative on either track, if the signal on that track is already in the "stop" position. Immediately, as the train passes beyond the junction, the block automatically clears behind it, and

[1] The development of the different methods of operating interlocking apparatus, in connection with the block system has been described in Chapter V, Part II, pp. 257–260.

[2] B. B. Adams. London Times, June 28, 1912.

the time-limit on each track becomes inoperative until the blocked section beyond the junction has been cleared. To insure that the time-relay is acting properly, a "proving-contact" is inserted in the track-circuit, which retains the signal in the rear in the "stop" position. An illuminated diagram in the signal-cabin shows the condition of the tracks, and small red lights at the junction indicate whether an approaching train has come to a stop or is operating the time-relay.[1]

The degree of efficiency that has been attained in the control of train-movements by the combination of the block system with interlocking apparatus may be inferred from experience on the New York Central Railroad. In March, 1907, 31,440 freight-cars were handled in a single day between New York and Buffalo, in addition to about 1000 passenger-trains. Forty-nine thousand men were employed in this service, exclusive of the clerical force and the men employed on construction-work. In the total distance of 440 miles, the operators in 225 towers controlled, on an average, 110 trains per mile of road.[2]

The sureness, or freedom from failure, in the operation of interlocking apparatus of this character, is shown in the following table:[3]

[1] General Signal Co., Rochester, N. Y.
[2] New York Times, March 24, 1907, p. 79.

[3] SWITCH AND SIGNAL FAILURES, HUDSON AND MANHATTAN RAILROAD

YEAR ENDING DECEMBER 31, 1915

Cause	Delays	Minutes	Average Operation per Failure
Signals	31	89	2,011,804
Automatic stops	7	13	4,567,113
Switches	15	41	289,983
Total	53	143	6,868,900

Railway Age Gazette, April 28, 1916.

CHAPTER VIII

WAR-TIME

MILITARY TRANSPORTATION BY LAND IN ANCIENT TIMES AND PREVIOUS TO THE RAILWAY ERA

FIVE years ago, there would not have been available material sufficient for a chapter on railroad efficiency in war-time. But to-day, railway efficiency for warlike purposes has undergone a wonderful development, and in no other country on a grander scale or under more favorable auspices than in the United States. To appreciate these facts in all their aspects, reference may be made to the earliest association of transportation with military operations.

From pre-historic sources, we obtain the impression that an invading army was not supplied to any great extent from the rear, but that it "lived on the country," ravaging it as the army marched and leaving a wake of desolation as it advanced. Its numbers were, therefore, limited by the resources of the country which it traversed, and its strength was otherwise restricted by the magnitude of the droves of asses or camels that formed its supply-columns. For the roads were but trails, impassable for any wheeled vehicles other than the light Egyptian chariots, and streams that could not be forded could only be crossed by ferries, for lack of bridges. The Pharaohs were able to conduct victorious campaigns because they had the use of water-transport, either upon the Nile, or on the Red Sea, or along the Syrian coast.

The first invasion of Greece by the Persians was by sea, with a fleet of 600 triremes, or galleys with three banks of oars, and 400 horse-transports, which landed 110,000 men for the Battle of Marathon. The second invasion was organized on a far more extensive scale. The resources of the vast empire of Xerxes were drawn upon from the banks of the Indus westward to the Ægean Sea and the waters of the Danube, from the Black Sea to the Red Sea and the Indian Ocean, and, in Africa, from the Egyptian outposts on the borders of Ethiopia. For a whole year, this host was assembling at Sardis, on the coast of Asia Minor. For two years, the women of Thrace were grinding corn for bread, and the flour was stored at fortresses on the line of march, with other supplies forwarded from Egypt and Syria by transports.

A pontoon-bridge, 4500 feet in length, with two roadways, was built across the Dardanelles at Abydos, and the peninsula of Mount Athos was separated from the Thracian coast by a canal of 4000 feet, to permit the passage of the fleet collected from Egypt, Phœnicia, Cyprus and the coasts of Asia Minor. For seven days and nights, the bridge at Abydos was thronged with soldiers on one roadway, and the baggage-trains on the other. After the crossing into Europe, the army numbered 1,700,000 footmen, 80,000 cavalry, 20,000 desert Arabs on camels and a force of chariots. There were 1500 triremes, 3000 fifty-oared vessels and unnumbered supply-ships and horse-transports, which kept along the coasts to supply the marching troops.

The host of Xerxes was probably the most numerous body of men that was ever organized in a single army. It took four months to march from the Dardanelles to Athens, a distance of about 480 miles, — an average of four miles a day. After the disastrous naval engagement in the Bay of Salamis, Xerxes covered the same ground in forty days in his homeward flight, which was an average of twelve miles a day. These two figures represent the maximum rapidity of movement of large armies and of individual travelers over the thoroughfares as they existed up to the time of the Roman Republic.

After an assumed existence of two hundred and forty-four years, the dominion of Rome, at the time of the expulsion of the Tarquins and the establishment of the Republic, had only extended over an area of about sixteen miles square, bounded by the sea, the Tiber and the mountains. For two hundred years thereafter, the Romans were almost constantly engaged in warfare with their neighbors. They might drive these from the plains but, in their mountain fastnesses, they awaited a favorable opportunity to resume hostilities. The Romans could gain no dominion over them nor even a permanent peace, only a truce for a term of years.

In 309 B.C., a Roman consul constructed a carriage-road out of the city across the adjacent marshes to the highlands. This was the beginning of the famed Appian Way, which was gradually extended southward into the enemy's country. The Romans had grasped the idea of securing their hold upon their conquests by establishing strategic lines of communication, which eventually radiated from the gates of the Eternal City to the farthermost bounds of their empire. Over these substantial highways, which bridged the smaller streams, armies moved with certainty and celerity, accompanied by siege-trains and by supply-trains of heavy wheeled vehicles, instead of pack-animals. Long after the Empire had been overrun by hordes of barbarians, the Roman roads facilitated communication until they were neglected beyond repair, though to this day portions of them are still passable.

The lack of roads in the Middle Ages prevented the movement of large armies with their supplies. Medieval warfare was carried on principally by small bodies of armored knights, who preyed upon the countries which they invaded. More important campaigns were based upon communication by sea, as were the Crusades upon the Mediterranean, while the long-continued warfare of England against France was sustained by transports from the Channel ports to Bordeaux. It was not until the middle of the Sixteenth Century that carriages began to supersede saddle-horses and horse-litters, and wagons to supplant pack-animals. As late as 1776, it required six weeks for a wagon with eight horses to make the round trip of about 420 miles between London and Edinburgh at an average rate of ten miles a day.

At the time of the French Revolution, the maximum rapidity of movement of large armies did not much exceed that of the army of Xerxes. The first carriage-road across the Alps, between Switzerland and Italy, was the military road over the Simplon Pass, constructed by Napoleon's orders in 1800-1807. At that time, fourteen days were allowed for a regiment to march from London to Liverpool, a distance of about 200 miles. About that period, a new era was inaugurated in road-making by Telford and Macadam, which was followed by extensive improvement in the means of communication in France. Rapidity of movement was, however, still limited by the muscular power and vital energy of man and beast, until the advent of transportation by rail and steam.

Early European Use of the Railway for War Purposes

Railroad construction in Europe was developed by the commercial activity that ensued upon the cessation of warfare after the Battle of Waterloo. As early as 1833, Harkort, a Westphalian, published a scheme for the construction of a railway along the right bank of the Rhine between Mainz and Wesel, which contained the following statement: "Any crossing of the Rhine by the French would then scarcely be possible, since we should be able to bring a strong defensive force on the spot before the attempt could be developed. These things may appear very strange to-day; yet in the womb of the future, there slumbers the seed of great developments in railways, the results of which it is, as yet, quite beyond our powers to foresee."[1] In 1833, in the French Chamber of Deputies, General Lamarque declared that the strategical use of railways would lead to "a revolution in military science as great as that which had been brought about by the use of gun-powder"; and M. de Bérigny asserted that, "An army, with all its material, could, in a few days, be transported from the north to the south, from the east to the west, of France." In 1842, M. Marschall, in advocating the construction of a line from Paris to Strasburg, said, "the German Confederation is converging a formidable system of railways from Cologne, Mayence and Mannheim. Twenty-four hours will suffice to concentrate on the Rhine the forces of Prussia, Austria and the Confederation, and on the morrow an army of 400,000 men could

[1] See "The Rise of Rail Power in War and Conquest, 1833–1914." E. A. Pratt. London, 1916.

invade our territory by that breach of forty leagues between Thionville and Lauterburg, which are the outposts of Strasburg and Metz. Three months later, the reserve system organized in Prussia and in some other of the German States would allow of a second army being sent of equal force." In the same year, Pönitz published a work in Saxony on the use of railways in war, in which, in a time of profound peace, he proposed the construction of a system of strategical lines for the protection of the German frontiers against France and Russia. In this work, he said, "We have to look to these two fronts; and, if we want to avoid the risk of heavy losses at the outset, we needs must also at the outset be prepared to meet the enemy there with an overwhelming force." [1]

Notwithstanding these repeated warnings, the French government attached so little importance to the strategical value of railways for national defense that, in 1844, von Moltke wrote to his brother that whilst Germany was building railways, the French Chamber was only discussing them; and when Germany had 3300 miles of railway in operation, France had only about 1000 miles. Nor were the military authorities in Germany in agreement as to the usefulness of railways in actual warfare. In 1847, a leading German military writer declared that the best organized railway could not carry 10,000 infantry for 60 English miles in 24 hours. "As for the conveyance of cavalry and artillery by train, that would be an impossibility."

At the opening of the Liverpool & Manchester Railway, in 1830, a regiment was conveyed 34 miles in two hours, which would have required a journey of two days on foot. In 1846, a Prussian army-corps of 12,000 men, with horses, guns, road-vehicles and ammunition was moved to Cracow on two lines of railway. In 1849, a Russian corps of 30,000 men and its equipment was taken by rail from Poland to Moravia, to a junction with an Austrian army and, in the winter of 1850, an Austrian army of 75,000 men, 8000 horses and 1000 vehicles was transported from Hungary and Vienna to the Silesian frontier. In the following year, a division of 14,500 men, 2000 horses, 48 guns and 464 vehicles was taken by rail from Cracow for a distance of 187 miles in two days. Allowing a march of twelve miles a day and one day's rest in seven, this movement would have occupied fifteen days.

In the Italian campaign of 1859, railways were conspicuous in actual warfare, both strategically and tactically. "Thousands of men were carried daily through France to Toulon, Marseilles or the foot of Mont Cenis; injured men were brought swiftly back to the hospitals. The railway cuttings, embankments and bridges presented features of importance equal or superior to the ordinary accidents of the ground, the possession of which was hotly contested." [2] In 86 days, the French railways

[1] Pratt, p. 5.

[2] Major Millar, R. A. V. C. Journal Royal United Service Institution, Vol. V, pp. 269–308. London, 1861.

transported 604,000 men and 129,000 horses with a total of 2636 trains, including 253 military trains. In ten days, the Paris-Lyons Railway moved a daily average of 8421 men and 512 horses, without interruption to the ordinary traffic and with a maximum of 12,138 men and 655 horses. 75,966 men and 4469 horses were transported by rail in ten days from Paris to the Mediterranean, or to the frontiers of the Kingdom of Sardinia; it would have taken sixty days for them to perform the same journey by highways. This rate of transit was about twice as fast as the best achievement recorded up to that time on the German railways. The men were described as leaving the station at Turin with none of the fatigue or reduction in numbers which would have occurred in marching. On the Austrian side, the First Army Corps of 40,000 men and 10,000 horses occupied fourteen days on the journey by rail from Vienna to Verona, having to march 83 miles from Innsbruck to Botzen, including the Brenner Pass over the Alps. The same journey would have taken 64 days, marching all the way.

Railway efficiency in these European wars was unfavorably affected by the lack of sufficient second track, station-accommodation and equipment, and by the want of coöperation of the military staff with the railway officials; but far more by a failure to work out a detailed scheme of organization, in advance of its being put in effect. From a combination of several of these causes, trains were blocked or delayed, stations were congested with supplies that should have gone forward, and needed reinforcements were kept waiting because of the delay in the return of empty equipment. It frequently happened that the transportation of troops occupied more time than if they had marched, and that they reached the front unaccompanied by necessary supplies. As a consequence, important military movements were retarded or frustrated.

Development of Railroad Strategy during the American Civil War

The use of railroads in warfare, on an extended scale, really began with the opening of the Civil War in the United States, in 1861. The northern frontier of the field of action was formed by the Chesapeake Bay, the Potomac and the Ohio rivers. This frontier line of over 1200 miles was paralleled for the whole distance on its northern side by railroads and, with the exception of about 350 miles west of Washington, it was also covered by navigable waters which were dominated by the federal forces. The Mississippi River separated the eastern and the western portions of the seceding states. At a short distance above Cairo, on the Ohio River, the Cumberland River gave access to Nashville, and the Tennessee River to the northern border line of the states of Mississippi, Alabama and Georgia, although these navigable waters into the heart of the Confederacy were defended by fortifications.

The continuous line of defense for the South was defined by the railway lines through Virginia and along the southern border of Tennessee to Memphis for nearly 900 miles; and from Memphis to New Orleans for 400 miles. Toward the seacoast, sealed by blockades, the railroad line extended from Fredericksburg through Richmond, Petersburg, Wilmington, Charleston and Savannah for 650 miles; and thence through Southern Georgia and Middle Florida for 280 miles to St. Marks, on the Gulf of Mexico. In a general way, this region was thus surrounded on three sides by a continuous line of railroads for over 2000 miles, a situation which had never before existed in warfare.[1]

Toward the south, peninsular Florida extends for over 400 miles, its eastern border then accessible from the interior only by light-draft vessels for 125 miles up the St. John's River. This peninsula was covered from Fernandina, on the Atlantic coast, to Cedar Key on the Gulf of Mexico, by a railroad line of 150 miles, which was crossed by another railroad of 81 miles from Jacksonville to Live Oak, where it connected with the line from Savannah. Otherwise, this vast territory was for the most part an unexplored region of lakes and impenetrable swamps, surrounded by lagoons and sand-bars. Virtually, the same conditions prevailed along the Gulf coast to the vicinity of Mobile, whose fortifications protected the interior navigation in the State of Alabama, as those at New Orleans did the ascent of the Mississippi River; and there was an interior navigable route between those ports.

The only points at which the Southern railway system approached that in the Northern States were at Columbus, Ky., on the Mississippi River, at Louisville, on the Ohio River and by the Orange & Alexandria Railroad at Alexandria, eight miles below Washington; but at each place on the five-foot gauge.[2] The Shenandoah Valley Railroad lay west of the Blue Ridge for 51 miles from Harper's Ferry, on the Baltimore & Ohio Railroad, to Strasburg. Trains also ran into Strasburg from the Orange & Alexandria Railroad via Manassas Junction, 26 miles from Alexandria and 61 miles from Gordonsville on the Virginia Central Railroad, then open to Clifton Forge, 193 miles from Richmond. This line was, however, of five-foot gauge and arrived at a separate terminal in Strasburg. The Richmond, Fredericksburg & Potomac Railroad terminated at Aquia Creek, on the Potomac River, about 35 miles south of Washington. Where these lines across the war zone touched the Mississippi River system, like "bridge-heads" upon roads across navigable streams, they constituted veritable strategical points of offense or defense.

[1] The total railway mileage in the Confederate States in 1861 was about 6000 miles. — Railway Age Gazette, May 22, 1917.

[2] The Long Bridge over the Potomac River at Washington was made available for railroad trains at the time of the opening, July 2, 1872, of the Alexandria and Fredericksburg Railroad, from Washington to Quantico on the Richmond, Fredericksburg & Potomac Railroad.

The first break in the railroad line of defense was achieved at Corinth; and, as it proved to be the ultimate cause of the downfall of the Southern Confederacy, it is worth while giving special attention to this notable instance of the relation of railroad transportation to modern warfare. Corinth is 94 miles east of Memphis and 20 miles west of the point at which the Tennessee River turns sharply from the east northward to its junction with the Ohio River, 45 miles above Cairo. The quadrilateral area bounded by the Tennessee, the Ohio and the Mississippi rivers and by the Memphis & Charleston Railroad, was bisected by the extension of the Mobile & Ohio Railroad from Corinth for 140 miles to Columbus, Ky., on the Mississippi and about 30 miles below the confluence of the Ohio. This outpost of the Confederacy was protected by the defenses on Island No. 10 in the Mississippi River, as it was on the Tennessee River by Fort Henry. Fort Donelson, on the Cumberland River, was but 12 miles east of Fort Henry by land, and protected Nashville from an ascent of that stream. The Memphis & Charleston Railroad paralleled the Tennessee River for 217 miles from Corinth to Chattanooga, crossing the river at Decatur, Ala., 95 miles from Corinth, and again at Bridgeport, 28 miles west of Chattanooga, on the track used jointly from Stevenson with the line from Nashville. The Tennessee was navigable to Chattanooga with the exception of the obstruction caused by the Muscle Shoals, about 50 miles west of Corinth.

The surrender of Forts Henry and Donelson in February, 1862, and the destruction of the bridges over the Tennessee and the Cumberland rivers on the line from Memphis to Louisville, compelled the withdrawal of the Confederate forces to the south of the Cumberland River and exposed to attack the whole line of the Memphis & Charleston Railroad from Memphis to Chattanooga. In March, 1862, Grant ascended the Tennessee River and fought the indecisive battle of Shiloh on April 6 and 7. On May 30, the Confederates evacuated Corinth and fell back to Tupelo, 50 miles south on the Mobile & Ohio Railroad.

The loss of Corinth deprived the Confederacy of its only continuous line of railway communication from the Mississippi River to the Atlantic Ocean. It was now dependent upon the railroad from Vicksburg for 244 miles to Selma, which was 50 miles west of Montgomery by land, but perhaps double that distance by the Alabama River. At Jackson, Miss., this line was crossed by the New Orleans, Jackson & Great Northern Railroad to Grand Junction on the Memphis & Charleston Railroad and beyond to Jackson, Ky., on the Mobile & Ohio Railroad, north of Corinth, with a branch from Grenada to Memphis. At Meridian, 140 miles distant, the line from Vicksburg crossed the Mobile & Ohio Railroad.

The New Orleans, Jackson & Great Northern Railroad formed the first line of defense toward the Mississippi River and the Mobile & Ohio Railroad the second; but the Union forces held both New Orleans and

Mobile, also the line of the Memphis & Charleston Railroad, so that Mississippi and that part of Alabama west of the Alabama River were exposed to attack from the Gulf of Mexico and from the Mississippi River at Memphis; except as it was protected by the cross-line from Vicksburg to Selma. This railroad was now the sole means of communication with the seceded states west of the Mississippi, which became completely isolated after the surrender of Vicksburg on July 4, 1863. From that date, the Confederate line of defense westward was formed by the railroad from Blakeley, at the head of Mobile Bay, through Montgomery and Atlanta to Chattanooga.

With the loss of Corinth, Chattanooga became the bastion of the outer line of defense of the Confederacy at the angle formed by the railroad line southward through Atlanta and Montgomery to Mobile Bay and the line eastward through Knoxville and Bristol toward Richmond. The Federal occupation of Knoxville cut this latter line, contemporaneously with the surrender of Vicksburg and the isolation of the seceding states west of the Mississippi River. The whole of Upper Georgia and Western North Carolina was now defenseless. Chattanooga had become merely an outpost of the last interior line of railway communication in the Confederacy, passing through Atlanta, Augusta, Columbia, Charlotte, Greensboro and Danville to Gordonsville and Fredericksburg.[1] At Branchville, S. C., this line was within 70 miles of the seacoast at Charleston, and there were two breaks of gauge, one at Charlotte and the other at Greensboro. There was an alternative line from Kingsville, S. C., 23 miles below Columbia, through Wilmington and Petersburg to Richmond, with break of gauge and ferry-transfer at Wilmington.

The first shot in the Civil War was fired on January 9, 1861, at a transport attempting to succor the Federal garrison of Fort Sumter in Charleston Harbor. On November 7, 1861, the Federal forces reduced the defenses at the entrance to Port Royal Harbor and occupied the islands along the coast of South Carolina; but failed in repeated efforts to break the line of railroad between Charleston and Savannah. On November 16, 1864, Sherman began his memorable march from Atlanta. A month later, he besieged Savannah and compelled the evacuation, in February, 1865, of the entire railroad line along the coast. The railroad line of defense in Virginia had likewise been firmly held against successive attacks. They began on July 21, 1861, at Manassas Junction, on the Orange & Alexandria Rail-

[1] The connection between Greensboro and Danville, known as the Piedmont Railroad, was authorized as a military measure by an Ordinance of the North Carolina Convention, February 8, 1862, and was sanctioned by the Virginia Legislature. On February 10, 1862, the Confederate Congress appropriated $1,000,000 in bonds to secure the connection but, as this aid was unavailable, the charter was taken over by the Richmond & Danville Railroad Company, and the road was opened on May 19, 1864. This information has been furnished by Col. T. M. R. Talcott, formerly General Superintendent of the Richmond & Danville Railroad.

road, extending thence eastward to Fredericksburg and then southward, until the line was at length breached at Petersburg in April, 1865, with the surrender of Lee's army. Step by step, with the loss of strategic positions on the several interior railway lines of communication, extensive areas of territory had been abandoned until the whole country was lost; yet the line along the Atlantic coast remained intact until the end. Thus, it may justly be asserted that the doom of the Southern Confederacy was written in the Book of Fate with the loss of Corinth.

From this account, it will be seen how entirely dependent the Southern States were upon railroads for lines of internal communication, owing to lack of substantially constructed highways and a system of internal navigation. The vulnerability of railway lines seriously diminishes their strategical value. At one time, at least one-half of the Federal forces in Kentucky and Tennessee was engaged in the protection of the railroads from Louisville southward. Railroad communication between the bases of supplies and the fighting line may be interrupted at critical moments by cavalry raids, but the navigation of inland waters can not be so obstructed. The superiority of navigable streams in this respect was proven by the ready means of access afforded into Confederate territory from the Western States by the Mississippi River and its tributaries. Steamboats might speedily place troops and supplies in indefinite numbers wherever transport barges could reach the river-banks and, in an emergency, could readily transfer a retreating army to a rallying point on the opposite shore. Armored gunboats successfully passed Confederate batteries from Island No. 10 to Vicksburg and Port Hudson, and were instrumental in depriving the Confederacy of support from the seceding States west of the Mississippi. Yet the railroad lines along the Atlantic coast were held against attacks from the sea until the evacuation of that region was made necessary by Sherman's invasion from the rear.

Military Operation of Railroads in the Civil War

As the seceding states drifted into civil war, neither of the parties to it formed an adequate conception of the magnitude of the operations that it would involve, or of the character and organization of the preparations essential to its efficient conduct. This fact was made conspicuous in the course pursued with reference to railway transportation. There was no thought of the railroad as a special instrumentality in warfare, beyond its use in time of peace. The government departments utilized it separately like any other shippers, and troops were handled after the manner of holiday excursionists.

Thomas A. Scott, Vice President of the Pennsylvania Railroad Company, was appointed Assistant Secretary of War, with especial reference to the control by the government of the railroad and telegraph lines, but resigned the position January 1, 1862. In that month, the President was authorized by Congress to take possession of any or all railroad or telegraph lines, "when in his judgment the public safety may require it," but he seems only to have exercised this authority within the field of military operations, and there was great need for it. Within the war zone, the railroad train was treated as a mere adjunct to the quartermaster's department, to be handled like a wagon-train. As a consequence, it was estimated that by conflict of authority, the military railroads were not operated to one-third of their capacity.

Herman Haupt, a distinguished railway engineer and a West Point graduate, was placed in charge of the railroads in the Department of the Rappahannock, but General Pope interfered to such an extent that Haupt resigned and went home. Ten days later, the Secretary of War put him in charge of all railroads in the territory occupied by the Army of the Potomac, with the rank of Brigadier General of Volunteers. A general called on him to move 10,000 men and their equipment eighteen miles to the battle front. Haupt said that the men could march there in less time than by train, and with less danger from attack on the way. The general seized the train and threatened Haupt with arrest. Haupt reported to General Halleck that the many embarrassments, irregularities and blockades were due —

1. To sending supplies to advanced terminals before they were required;
2. To lack of promptness in loading and unloading cars;
3. To detaining trains beyond schedule time.[1]

To remedy this condition, the Secretary of War issued an order saying, "No officer, whatever may be his rank, will interfere with the running of cars, as directed by the superintendent of the road, under penalty of being dismissed."

On February 11, 1862, D. C. McCallum, General Superintendent of the Erie Railroad, was appointed Military Director and Superintendent of Railroads in the West, with the rank of Colonel. On November 10, 1862, the Secretary of War issued a special order requiring commanding officers to furnish working parties to load and unload cars without delay, to guard the railroad lines and equipment, and under no circumstances to permit of interference with railway operations. Any officer who should neglect his duty in this respect was to have "his name stricken from the rolls of the army." McCallum said that without this order "the whole railroad system would have been not only a costly but a ludicrous failure.

[1] A single-track line was blocked three hours by a train waiting for an officer's wife to look for rooms. A paymaster established his office in a car on the main line and had to be removed by troops. Union soldiers tore up sidings, broke switch-stands, used locomotive-wood for fuel and washed their clothes in the streams that supplied the water-stations, so that the trains were stopped by the locomotive-boiler foaming with soapy water.

The fact should be understood that the management of railroads is just as much a distinct profession as the art of war."

The United States Department of Military Railroads was subsequently managed by Brigadier General Haupt with the Army of the Potomac, and McCallum, as Brevet Brigadier General, with the Army of the Mississippi, with complete and exclusive control of the operation of all military railroads, which, at the close of the war, numbered 2105 miles of line with 22,000 men.[1]

No serious effort was made in the Southern Confederacy to organize railway operation as a military measure. As the Confederate forces retreated from the West and the tracks were torn up, the equipment which had been withdrawn was placed under the charge of a few railroad officials who were attached to the quartermaster's department with military titles. This equipment was utilized in a desultory way for the transportation of cotton to be shipped through the blockade for the purchase of munitions of war. Usually, each regimental or post quartermaster, or each officer in a separate command, disposed of the railway transportation within his reach to suit himself. Some attempts were made to remedy this situation by officers in the higher commands. When the South Carolina coast was evacuated, Lieutenant General Hardee placed the railroad movement solely under his Chief Quartermaster, with a railroad official in direct charge of the train-service and of the equipment then under military control.

It was amply proven in the Civil War that it was the function of army officers to determine the points to which troops and supplies should be moved, and for the railroad officers to determine the manner in which that service should be performed. For this purpose, the railway staff should be organized, like the medical staff, as a distinct branch of the non-combatant service. As an instance of what can be accomplished in this way, it may be mentioned that, in September, 1863, when the Federal forces in Chattanooga were being sorely pressed, Hooker's corps of about 23,000 men was transported by rail from Virginia to their assistance in eight days; a distance of 1200 miles with a break of eight miles between Alexandria and Washington.

The limit is soon reached at which an army can be separated from its base of supplies, relying solely upon wagon-trains. Sherman said that,

[1] United States Military Railroads in 1865

Lines in Virginia, Maryland and Pennsylvania	611 miles
Lines in Kentucky, Tennessee, Georgia, Mississippi and Arkansas	1201 miles
Lines in North Carolina	293 miles
Total	2105 miles

Seventeen thousand men were engaged in this service in the West and 4500 in Virginia and North Carolina.

The railroad lines used for military purposes were returned to their owners by Executive Order, August 8, 1865.

"No army dependent on its wagon-trains can operate more than a hundred miles from its base, because the teams going and returning consume the contents of the wagons." Yet Sherman marched from Atlanta to Savannah, a distance of about 300 miles in five weeks, dependent upon the supplies that he carried and upon plundering the country through which he passed.[1] After the Battle of Shiloh and the evacuation of Corinth, Grant was unable to pursue his retreating enemy more than forty miles, on account of the difficulty in providing his army with food and ammunition as the distance increased from his base of supplies on the Tennessee River. His army of 30,000 men required 1100 six-mule wagons to keep it supplied at a distance of two days from its base, and 1900 wagons at a distance of three days. Such an army could not march more than two or three days without shifting its base along a railroad or navigable stream which was securely connected with a permanent base in the rear.[2]

The efficiency of the United States military railroad organization was conspicuous in the restoration of interrupted lines of communication. For this work, an organization was developed which has influenced the course of recent warfare. In Northern Virginia, General Haupt relaid three miles of track in three days with inexperienced soldiers, including the cutting of 3000 ties. He rebuilt a bridge of 120 feet span and 30 feet high in fourteen hours, and a trestle-work 414 feet long and 82 feet above water-level in nine days. This trestle was again destroyed and rebuilt in forty working hours. This performance was accomplished by the preparation of standard structural parts which went into place without fitting them. In this way, nineteen bridges on the Northern Central Railroad, which had been destroyed during the Battle of Gettysburg, were renewed by noon on the day after the Confederate retreat. The situation in this respect was even more remarkable in Kentucky and Tennessee, where the railroads were repeatedly destroyed almost immediately after they had been rebuilt.[3]

[1] Sherman left Atlanta with 63,000 infantry, 5000 cavalry, 600 ambulances and 65 guns, accompanied by 600 baggage wagons. He had a supply-train of 2500 six-mule teams, with bread for 20 days, sugar, coffee, tea and salt for 40 days and 3 days' forage in grain; also with droves of cattle for a month's subsistence.

[2] The weight of necessary supplies averaged four pounds a day per man. A six-mule team hauled 2000 pounds, — a supply for 500 men. After the army was a day's haul from its base, it took two days for the round trip, and could therefore supply but 250 men daily, or 125 men at a distance of three days' haul. To supply an army of 50,000 men at two days' from the base required 400 wagons for this purpose only. Such an army required 8000 horses for its cavalry and artillery, each consuming 25 pounds of forage daily; a load also for 400 wagons. The 4800 mules, hauling these 800 wagons required 180 wagons to carry their own food, etc.

[3] During the year 1862, there were but seven months in which trains could run from Louisville to Nashville, 185 miles. Every bridge and trestle-work on the main line and branches had been destroyed and rebuilt within the year; many of them three or four times. Stations and cars were burned, locomotives demolished and a tunnel choked with rubbish for 800 feet.

In February, 1864, General McCallum supplied the army at Chattanooga from its base at Nashville, 151 miles away, with but 39 locomotives and 400 cars originally available, over a single-track line laid with a light U-rail on stringers badly decayed and an unballasted road bed, in such condition that derailments were of daily occurrence from spreading track. The maximum force employed in the transportation department was 12,000 men. There were 5000 men in the construction department, organized in six divisions, each in charge of an engineer with subdivisions under supervisors.[1] This organization was extended to Atlanta, 288 miles from Nashville. With it there were rebuilt 115 miles of track with thirteen sidings averaging eight miles apart, each with room for five to eight long trains and provided with a telegraph station. Storehouses and repair shops were built at Chattanooga and Nashville; the shops at the latter place being capable of accommodating a hundred locomotives and a thousand cars at one time. A rail-mill was also built near Chattanooga. The repair gangs were distributed at strategic points, so that a break could be repaired from either end. The Chattanooga River bridge, near Atlanta, 780 feet long and 82 feet high, was rebuilt in four and a half days. When Hood cut the railroad in Sherman's rear, he tore up ten miles of track in one place and twenty-five miles in another. These breaks were repaired in a week. In guarding the line, pickets were thrown out at exposed points and twelve sentinels were posted per mile with flags and lamps for signaling. Block-houses were built at each bridge and cross-road and at intervals along the line, and the right-of-way was kept clear of bushes.

For lack of efficient organization, the Southern Confederacy could show no such performance in railroad reconstruction. Sherman, in his march to the sea, destroyed every bridge and other railroad structure. Locomotives were either fired without water in the boilers or disabled by cannon shot. The rails were not connected by fish-plates but by chairs. As they were torn up, they were heated in the middle on piles of burning cross-ties. A chair fastened to the middle of a handspike by telegraph wire was slipped on each end of the heated rail, which was then twisted around the trunk of an adjacent tree.[2] It was a strange sight to look down a tangent upon a double row of these "Sherman neck-ties." In repairing

[1] A complete division consisted of six general officers, 356 men in the bridge and carpenter gangs, 356 in the track gangs, 13 in a masonry gang, 11 in a train crew, an ox-brigade of 20, and 15 at the water-stations; a total of 777 men.

[2] The Mexican revolutionists use a locomotive in tearing up track. A chain is passed around the opposite rails and made fast in the middle to a steel cable attached to the locomotive which, as it moves slowly backward, tears the rails loose and drags them into the center of the road. Many of them are bent and twisted in the process. Ties are piled upon them and beneath, saturated with oil and set on fire. Steel trusses are destroyed by boring holes in the masonry piers and charging them with dynamite, which is exploded by fuses connected with an electric battery.

the track, the rails were regained by cutting down the trees. They were then reheated and straightened. The kink in the middle was somewhat reduced by swaging, but there remained enough of it to be sensibly felt in a passing train. Railroad supplies were only obtained through the blockaded ports, and, being usually of British origin, were for the most part unsuited to American practice. The roads terminating in Charleston, S. C., used car-wheels cast from fragments of projectiles fired from the besieging batteries, and made brass machinery fittings from unexploded percussion fuse-plugs.

Armored cars were first introduced in warfare in August, 1862, when a bullet-proof car mounting a cannon was sent to the Army of the Rappahannock, but was found to be useless. After the capture of Newbern, N. C., two cars were protected with old rails, with slits for musketry fire on the sides and a shuttered port-hole in front, behind which a field-gun was mounted. These cars were pushed ahead of a locomotive in reconnoitring. Bullet-proof cabs were placed on locomotives for protection against attack from the side of the road.

The ambulance-car and the hospital-train were developed in the Civil War. In the first part of the war, the less-seriously wounded were carried in passenger-coaches. Those who were unable to sit up were lifted on stretchers or mattresses into box cars and laid on hay, straw, leaves or pine boughs; holes being cut in the sides of the cars for light and ventilation. Only ten patients could be properly cared for in a car, though twenty were often carried. Cars were then introduced with two or three tiers of bunks on each side. In March, 1863, stretchers were suspended from uprights by strong india-rubber rings, but were unsatisfactory on account of the motion of the train. In 1862, a car was placed on the Philadelphia, Wilmington & Baltimore Railroad, provided with a stove, locker and seat for attendants, which could hold fifty-one patients. Similar cars were put in use on other roads; some of them with twenty-four beds in two tiers, with the lower tier on the car seats. These cars were attached to the regular trains.

In 1863, a complete hospital-train was introduced on the Orange & Alexandria Railroad, converted from passenger-coaches, and with capacity for from five hundred to six hundred patients. There were special cars for the surgical staff, for a dispensary, store-room and kitchen, and ten ward-cars, with accommodation for thirty patients lying down, and as many seated. Two windows and the intervening panel were removed on each side of the car and replaced by a sliding door, through which the stretchers were carried. Such trains ran on regular schedules between Atlanta and Louisville, 474 miles, up one day and down the next. The locomotive-stacks were painted red, as also the cab and tender, with three red lights at night under the headlight. The Confederate troops never fired on them, but gave them passage when they were about to tear up the track. After the Battle of Chancellorsville, 9000 wounded were thus transported to Aquia Creek between June 12, 1863, at noon, and June 14, P.M. In twenty days following the Battle of Gettysburg, 15,000 wounded were distributed to hospitals in Washington, Harrisburg, Philadelphia and New York.

German and French Handling of Railroads in War 1864–1870

Experience in our Civil War had proven that, for efficiency in warfare, the railway staff should be organized, like the medical staff, as a distinct branch of the non-combatant service. Military attachés from the principal European governments had been present with both the Federal and the Confederate forces, yet they apparently gave this matter no serious attention, with the exception of the Prussian government, which formed a Railway Section of its General Staff for the war with Denmark in 1864.

This organization was further developed in the war with Austria in 1866. In this campaign, the movement of troops by rail was controlled by an Executive Commission, composed of a General Staff officer and a representative of the Ministry of Commerce, assisted by Line Commissions operating on the several lines of communication. The experience in this brief campaign, as in our Civil War, emphasized the fact that railway operations were too much interfered with by military officials. There was the same congestion of traffic from rushing supplies to the front in excess of requirements, delay in loading and unloading cars and unnecessary detention of trains and irregularity in train-service. Long trains of empty cars often blocked the running-tracks, and troop-trains were even dispatched in the wrong direction. The whole situation indicated an insufficient correlation between the military and the railway organizations.

In forecasting the invasion of France, von Moltke appointed a commission to draft a set of regulations for more efficient control of railway operations in time of war. The scheme thus elaborated, known as the Route Service Regulation, though approved in May, 1867, was kept secret until the outbreak of the War. Under this plan, the military transport service of every kind was placed under an Inspector General of Communications, assisted by a Director General of Railways.

The mobilization in 1870 was conducted on nine lines of communication. Between July 24 and August 3, 1200 trains conveyed to the frontier 350,000 men, 87,000 horses and 8400 guns and vehicles. Great difficulty was, however, experienced in provisioning the troops, notwithstanding the elaborate instructions to that end. Owing to the inveterate custom of rushing supplies indiscriminately forward, and the consequent congestion at the advance stations, the railway lines beyond the Rhine were blocked back to Cologne and Frankfort. On September 5, 1870, there were thus held in transit 16,830 tons of food-supplies for one of the invading armies, sufficient to supply it for twenty-six days, while the troops were suffering severe privation. Fortunately for them, the French had been equally improvident, and the Germans were saved from starvation by the capture of stores of supplies abandoned in the retreat of the French army. Afterward, in the siege of Paris, and during the impassable condition of the French railways, the invading army lived by plundering the country.

The weak points in the German organization were due primarily to the extensive authority assumed by the Inspector General of Communications with respect to the details of railway transportation and auxiliary matters; but a far greater defect was the lack of coöperation between the military and the railway officials. The service was improved by transferring the control of railway operations to an Executive Commission at General Headquarters; but the congestion at the front was not remedied until nearly the end of the War, when intermediate depots of supply were established at stations in the rear of the field of action, provided with sufficient yard and storage facilities.

In July, 1872, the Railway Route Regulation was amended by the creation of a separate military department charged with the operation and maintenance of the railway lines in the war zone, and with the control, in time of war, of the railway lines of communication, instead of dealing with nine separate Ministries of Commerce and fifty railway companies in the several German states. In this Regulation, a distinction was drawn between the railways in and near the field of action, which were placed under military control, and those on the rear lines of communication, on which the service was still to be conducted by the railway managements, with a military supervision of the movement of troops and supplies. This Regulation was reissued in January, 1899, in an amended form.

In March, 1908, there was published a series of Field Service Regulations in which the Railway Section of the General Staff was required to keep in touch with the railway authorities as to their facilities for military service, and was empowered to conduct such investigations by its own officers. In time of war it was to take charge of the preparations for military transportation through an Inspector General of Railways and Lines of Communication, who was to coördinate the activities of the military staff and of the railway managements, and also to define the limits between the railways that were to be conducted on a peace-footing and those that were to be subject to military control. A director of Field Railways was to supervise the railway service, as applied to military purposes, through twenty-one Line Commissions, each consisting of a staff-officer and a railway official. Upon the outbreak of war, each of these Commissions was to take charge of the railways in a specified district, under a Line Commandant. A "Home Base" was assigned to each army corps, from which in time of war its supplies were to be forwarded to Collecting Depots at the immediate rear of its field of action. The train-service was prescribed in such minute details as the supply of drinking-water at stations and the taking of carrier-pigeons on troop-trains. The Regulations were explicit as to non-interference of military officers with railway operation.

The French government had paid so little attention to the publication of the German Railway Regulations that it was without a plan for military railway operation when its territory was invaded. This matter was left to the railway managements, but they responded to the call vigorously and intelligently. On July 15, 1870, they were required to place their lines at the service of the Minister of War. Between July 16 and 20, there were dispatched 594 trains, carrying 186,620 men, 32,410 horses, 3162 guns and vehicles and 995 car-loads of supplies. But they were greatly hampered by the lack of coöperation on the part of the military staff.

In Germany, the troops had been concentrated at interior points, and thence transported to the front in complete units as a distinct operation. But in France, the movement was direct from the points of mobilization, with lack of organization and with much confusion. Sometimes, troops assembled at a station three hours before the appointed hour and, in the meantime, the men became intoxicated at the neighboring taverns; or else the trains would be kept waiting hours for an appointed movement. Previous information was not given as to the strength of a regiment to be entrained, and the number of cars would either be inadequate or insufficiently occupied or filled up with a motley assemblage of horses, ammunition and commissary supplies. Commanding officers left the entraining of troops to subalterns and, by traveling in more comfortable trains, became separated from their commands. The intermediate stations were filled with men who had purposely been left by their trains and who passed the time at the railway buffets. In August, 1870, the supply-trains at Rheims were plundered by a mob of over four thousand of these estrays.

Orders which were impracticable or conflicting were issued from different military authorities, and even by non-commissioned officers. Many orders were given to suit the personal convenience of the persons issuing them, or to meet some local contingency. A train was required to move a detachment ten miles to save the men from walking to an instruction camp, and demands were made for cars to be used as barracks. The congestion of traffic at advanced stations was far worse than it was in Germany. Close to the front, the tracks were occupied for miles by loaded cars and with continuing arrivals. While the Germans had appointed route-officers to enforce the unloading of cars, no such provision had been made in the French army. The cars were used as storehouses. A general kept the line blocked for hours by refusing to permit his men to be detrained in the snow. As a consequence, the Germans captured immense quantities of stores, and the cars in which they were loaded to the number of sixteen thousand.

British Railway Preparation for War and Subsequent Experience

In Great Britain, on account of the complete private ownership of its railway system, a different course was pursued in preparing for railway operation in war-time. As far back as 1842, an Act had been passed "for the better Regulation of Railways and for the Conveyance of Troops," known as "The Railway Act," which was the first legislation with reference to military railway transportation. In 1871, the control of railways in time of war was provided for by "An Act for the Regulation of the Regular and Auxiliary Forces of the Crown," known as "The Regulation of the Forces Act." This Act provided for taking possession of any railway property when, by an Order in Council, it was declared expedient for the public service, and for its operation "at such times and in such places as the Secretary of State may direct." The warrant for this purpose was to remain in force for one week only, but it could be renewed from time to time at the option of the Secretary of State. The National Defence Act of 1888 provided that traffic for military and naval purposes should have priority over other traffic on railways in the United Kingdom, whenever an Order for the embodiment of the Militia was in force and, under this Act, the railways were taken over by the Government in 1914.

The purpose in this legislation was the protection of the British Isles against invasion, and the subsequent organization had this object in view. In 1865, the Engineer and Railway Volunteer Staff Corps had been organized "for the purpose of directing the application of skilled labor and of railway transport to the purposes of national defence, and for preparing, in time of peace, a system on which such duties should be conducted." The corps consisted of officers only, who were civil engineers, contractors, officers of railway or dock companies or Board of Trade Inspectors of Railways. Under the Territorial and Reserve Forces Act of 1907, this corps became part of the Territorial Forces under the title of "The Engineer and Railway Staff Corps."

In 1896, this corps was supplemented by a smaller body, known as the "War Railway Council," intended to act in an advisory capacity to the Government departments. It consisted of the Deputy Quartermaster-General, as president, six railway managers, one Board of Trade Inspector of Railways, two members of the Engineer and Railway Staff Corps, the Deputy Assistant Quartermaster-General, one mobilization officer, two Naval officers and an officer of the Royal Engineers. This Council drew up a plan for the organization of a body of railway-staff officers, who were to act as intermediaries in the conduct of military transport under the name of the Railway Transport Establishment. The officers were entitled Railway Transport Officers (R. T. O.), and its chief, Director of Railways (D. R.). Under this plan, subject to instructions from his superior officer, the R. T. O. exercised an authority at his station that not even a general might question.

British Railway Operation during the Egyptian and South African Campaigns

At the outbreak of the South African War, in 1899, there were dispatched from Southampton about 235,000 men, 29,000 horses and 1000 vehicles. In a single day, five transports sailed with about 5000 men, with guns, horses and wagons, without overtaxing either the railway or the dock facilities. The success which attended this operation was attributed, in a great measure, to the presence of a Railway Transport Officer, as intermediary between the military and naval authorities and the representatives of the railway and dock service.

In 1912, the War Railway Council was superseded by a Railway Executive Committee, composed of eleven of the general managers of the principal railways, with the President of the Board of Trade as its official chairman. This Committee was authorized to prepare plans for assuming control of the railways by the Government, under the provisions of the "Regulation of the Forces Act" of 1871, and, in this event, to become intermediary with the railway companies, which were to retain the management of their lines. Through this Committee, control was assumed by Order in Council of August 4, 1914.

It was learned in the American Civil War that, as the lines of communication approached a field of action, the military element should predominate in the railway organization, which, however, should not lose its identity as a separate branch of the service. This requirement was fulfilled in Germany, in 1866, by the formation of battalions of railway troops, and in Great Britain, in 1882, by the conversion of companies of Royal Engineers into Railway Companies. These companies rendered valuable assistance to the Expeditionary Forces in Egypt in 1882 and in 1885, in conducting the regular train-service, in repairing damaged track and in conveying troops, and the sick and wounded.

In the autumn of 1884, when the attempt was made for the relief of General Gordon at Khartum, these Railway Companies, with the assistance of military details and native laborers, extended the Sudan Railway from its terminus, 33 miles beyond Wady Halfa, for 39 miles farther by December first, when the work ceased on the death of Gordon. In the following year, it was extended 24 miles to Akasha, when the whole line of the Sudan Railway was abandoned by the retreat to Wady Halfa. An attempt to relieve Khartum by the construction of a railway from the Red Sea at Suakim to Berber on the Nile had meantime broken down, owing to the defective organization for undertaking the work by contractors.

In 1896, when the Egyptian Government had decided upon the reoccupation of the Upper Nile Valley, the restoration of the line from Wady

Halfa, which had been destroyed by the dervishes, was intrusted to the Royal Engineers. The line was opened to Akasha in June. By August, it was extended to Kosha, 116 miles from Wady Halfa; and by May, 1897, 100 miles farther to Kerma. Two hundred and sixteen miles of railway had been constructed in thirteen months, including five months in which the work had been frequently interrupted, and with the transportation service maintained during construction.

In the meantime, it had been determined to stop the farther extension of the road around the Great Bend of the Nile, and to build a new line from Wady Halfa directly through the desert for 232 miles to Abu Hamed, a port on the Upper Nile. This work, begun in May, 1897, was completed by October 31, in the hottest season of the year, with an average of a mile and a quarter of track laid per day and a maximum day's work of 3¼ miles. By the farther extension of the line to the Atbara, in July, 1898, General Kitchener was enabled to concentrate troops and supplies for the Battle of Omdurman, September 2, with the subsequent occupation of Khartum and the overthrow of the Mahdi.

The Sudan Railway was the first railway to be constructed on an extensive scale solely for a strategical purpose. By the end of 1899, it was carried across the Nile into Khartum, and has since been extended 430 miles farther southward to El Obeid in Kordofan. By this means, a vast territory has been pacified and made of economic value which, had been for ages the field of internecine warfare. Its barbaric chiefs had defied the rulers of Egypt from the days of the early Pharaohs, and always successfully until its conquest was accomplished by the adaptation of the railway to offensive warfare.

The close of the Egyptian campaign in 1898, was followed by the declaration of war by the Boers in South Africa in October, 1899. Here the British Army had again to rely solely on long lines of communication by railway, converging on Pretoria for 1040 miles from Cape Town on the South Atlantic coast, for 740 miles from Port Elizabeth, to the east of the Cape of Good Hope, and for 511 miles from Durban on the Indian Ocean. For this especial service, a Department of Military Railways was established under the charge of Major Girouard, R.E., under whose intelligent and vigorous supervision the Sudan Railway had been built and operated. He was given the title of "Director of Railways for the South African Field Force," and was accompanied as Associate Directors by officers of the Royal Engineers who were experienced in railway construction and operation. The duties of the Department of Military Railways, as officially defined, were to serve as intermediaries in the technical military administration, to insure military efficiency in railway operation, and to meet military requirements without disorganization of the railway service.

A military Railway Controlling Staff was formed to coöperate with the staff of the Department of Military Railways. This staff consisted of an Assistant Director of Railways for Cape Colony, who was on the staff of the Director of Railways and also of the General Officer Commanding Lines of Communication. His headquarters was in the office of the General Traffic Manager of the Cape Government Railway. It was his duty to keep both of his superiors informed as to traffic conditions on the railways, to advise the General Officer Commanding (G. O. C.) as to the best methods for putting his orders into effect, to inform the railway officials as to military requirements and "to protect them from interference by unauthorized military officers," to see that proper regulations were issued to the Army for the efficient conduct of entrainments and detrainments, for the forwarding of stores and for keeping accounts as to the use made of the railways for military purposes. He was to be the sole channel of communication between the Chief Traffic Manager and the G. O. C. on the lines of communication. He was assisted by four Deputy Assistant-Directors on particular sections of the railway system.

Railway staff-officers were located at the principal stations to superintend important movements, and to serve as the sole means of communication between the Army and the station-masters, who were to take orders from no one else. These officers, though charged with the supervision of entrainments, etc., were not to interfere with the railway operatives in the management of the traffic. Being on the staff of the commanding officers, they were not controlled by the Director of Railways, and were without railway experience. Subsequently, they were more carefully selected in this respect and were placed under the orders of the Deputy Assistant-Directors.[1]

In the South African War, important strategic movements depended first upon gaining from the enemy the advanced lines of communication and upon restoring them for operation, and then upon repairing them as fast as they were interrupted by raiding parties. In this service, the military railway organization met with the ever-recurring evil of injudicious forwarding of supplies in large quantities to advanced stations before they were required. The lack of sufficient equipment was intensified by holding these supplies in the cars and to the serious detriment of military operations, until an order was issued that nothing should be shipped to the front without special permission from the Chief of Staff, Lord Kitchener. He was informed daily of the number of cars that were available, and allotted them to the several military departments in accordance with their requisitions and the traffic conditions prevailing on the line. Troop-movements were especially arranged so as not to interfere with the transportation of supplies and, as far as practicable, were made by marching.

The railways taken from the Boers, which eventually included over 1100 miles of line, were operated as a system of Imperial Military Rail-

[1] A scheme for military railway operation proposed in 1903 by Major W. D. Connor, Corps of Engineers, U. S. Army, is given in Appendix VIII, Note I.

ways by the Department of Military Railways. From the time that these lines were brought under British control, until August 31, 1900, they had transported 177,000 passengers, 86,000 animals and 520,000 long tons of supplies; and were operated by a staff of 18,000 officers and men. For lack of a trained force at the beginning of the War, in sufficient numbers, the deficiency was supplied by men from the fighting forces with some railway experience and, to a considerable extent, men were necessarily retained who had been employed under the former Netherlands Railway Company, upon whose loyalty there was no reliance. The difficulties encountered in railway operation with such an ill-assorted staff of employees induced Sir Percy Girouard to recommend that, in time of peace, a reserve of experienced railway men should be registered and paid a retaining fee for military service in time of war either at home or abroad.

The destruction of railway property in the South African War far exceeded that which had been experienced in the Egyptian campaign. The newly-introduced explosive, dynamite, was used for this purpose by the Boers to such an extent that special measures were adopted for the speedy restoration of the lines of communication. The Railway Corps was augmented by the establishment of a Railway Pioneer Corps of miners, artisans and laborers. The Field Railway Section, which had been organized for railway operation in the war zone, was assigned solely to reconstruction service, and controlled native laborers to the number of twenty thousand. As the Boers evacuated Bloemfontein in March, 1900, they destroyed the railroad line for one hundred and eighty miles, wrecking fifty bridges and demolishing the equipment. By the time that the line had been repaired to Johannesburg, they raided it again, destroying about thirty miles; and these attacks were repeated for months.

For the reconstruction, work-trains properly equipped were stationed at convenient sidings with gangs of from 30 to 100 men under the command of the Royal Engineers, who hastily made temporary repairs and were followed up by the Railway Pioneer Regiment. The patrols on the line promptly informed the nearest military post of any break or threatened raid. This information was telegraphed to the Deputy-Superintendent of Works, who immediately ordered a construction train to the point of danger.[1] Where important bridges were damaged, the immediate exigency was met by deviation over low-level structures built of sleepers

[1] On January 1, 1901, at 2.30 A.M., notice was recieved at Bloemfontein of a break in the line, 63 miles distant. By 8.00 A.M., the break had been repaired. Rail-communication with Johannesburg was restored within eleven days after Lord Roberts had made his way there, and the line to Pretoria was restored to use within sixteen days of its occupation. The advance of 265 miles from Bloemfontein to Johannesburg was made in forty-two days. In the meantime, temporary repairs had been made to 27 bridges, 41 culverts and 10 miles of line, including seven deviations of from 200 yards to two miles. From June 6 to November 15, 1900, the railway lines were damaged one hundred and fifteen times, but without material interruption of traffic beyond the suspension of night trains.

and rails. The more permanent repairs were made with standardized timber-parts, and a stock of rails was kept on hand for one hundred and fifty miles of track. In the region of guerrilla raids, the line was protected by block-houses, at first for the defense of bridges, but subsequently the whole of the lines were provided with them in the Transvaal and in the Orange River Colony.

Armored Cars and Hospital Trains

The introduction of armored cars in the American Civil War was extended during the Boer War to the use of armored trains. They were first used for scouting and were sent for considerable distances without support. As a consequence, one of the trains was destroyed by the Boers. Eventually there were twenty of these trains, converted by the addition of six-inch guns into armored batteries which, with more experience in methods of control and operation, were of greater practical use. They were at first placed under the orders of officers commanding sections of the line, who frequently rushed them out regardless of train-regulations and even without a "line-clear" message. They even made use of the trains to inspect posts on the main line, blocking the traffic while the inspection was being made.[1] Such instances were so frequent that they were said to have caused "more interruption than the enemy themselves." It finally became necessary to appoint an Assistant-Director of Armored Trains, who reported only to the Commander-in-Chief and to the Director of Railways, and the use of armored trains was definitely regulated.[2]

The armored trains, in conjunction with the block-houses, rendered invaluable service in the protection of the railway lines. "The enemy disliked them intensely and the presence of an armored train had a great moral effect." As far as possible, there was included in each ordinary train a special gun-truck on which was a pedestal-mounted quick-fire gun with an escort. The train also carried a machine-gun at each end, with a lateral sweep of fifty to eighty yards. Armor-plates were hung on each side of the locomotive-cab, and the first train out in the morning pushed two or three cars in front as a precaution against mines laid overnight.

The armored car has been developed into a "fortress train" on the Italian coast of the Adriatic Sea, where the railway line affords a protection to the coast for about five hundred miles. The battery-cars are of special construction, mounting heavy guns and aircraft guns, protected by shields and concealed under tarpaulins, the ammunition being similarly protected. The crew, composed of seventy seaman-gunners, is quartered

[1] When a large drove of cattle was being sent to Pretoria, they were driven beside the track under convoy of an armored train, and the entire length of the Delagoa Bay line was blocked until the drove had reached its destination.

[2] See Appendix VIII, Note II.

on the train, keeping watch as on shipboard. The train is equipped with a wireless outfit, signal-flags and appliances for tapping the telegraph and telephone wires. The lookout man is stationed on an extension-ladder at an elevation of fifty feet. Whenever the signalman or the coast-guard reports the approach of an enemy's ship or aeroplane, the train moves to the nearest point and opens fire. Before firing, special braces are thrown out to take up the recoil and the position of the train is frequently shifted before the enemy can obtain the correct range.[1]

Hospital-trains, which had been introduced in the American Civil War, were, in the South African War, either adapted from the ordinary passenger-equipment or else constructed for the purpose. One of these trains, composed of carriages 30 feet in length and 8 feet in width for the 3½-foot gauge, was arranged with one car divided into compartments for stores, nurses, and invalid officers; one into compartments for medical officers, with dining-room and dispensary; four ward-cars with beds arranged in three tiers; and a kitchen-car with a compartment for the guard. The trains carried supplies for two to three weeks. One of these trains ran 114,359 miles in 226 trips between November 22, 1898, and the end of August, 1902, carrying 10,796 patients of whom only seven died *en route*. The hospital-service was classed as permanent hospital-trains, specially constructed; temporary hospital-trains, from converted carriages; ambulance-trains, improvised at rail-head with internal fittings that could be readily fixed or dismounted for "lying-down" cases; and ordinary carriages for slightly wounded or convalescent patients.

At the beginning of the present war, there were only seven ambulance-trains in France. Even in September, 1914, wounded men were crowded into box cars where they lay, dead and living together, for three to four hours. By the middle of 1915, there were two hundred and fifty hospital-trains, divided into three classes; permanent trains for the badly wounded; semi-permanent trains for "lying-down" cases; improvised trains for those who could sit up. As the wounded were brought from the front in motor-ambulances, they were tagged with a description of the patient—on a white card for slight wounds; on a red card for serious wounds; on a blue card for those of medium gravity. They were then forwarded to nineteen distributing stations. The French hospital-trains consisted of sixteen cars, made up as follows: next to the locomotive, a provision-car; then, successively, the surgical staff, the kitchen-car, four ward-cars, a pharmacy and operating car, four ward-cars; and the remaining cars accommodated the hospital-staff of thirty-three persons and the train-crew. The ward-cars were of the center-corridor type, each with thirty-two beds.

The British wounded were carried from the French front to the Channel ports, thence by hospital-ships and by ambulance-trains to interior hospitals in England. The trains on both sides were of high-grade equip-

[1] Railway Age Gazette, May 4, 1917.

ment. A typical train was made up of an infectious-ward car, train-crew car, kitchen and stores car, five cars for sitting-up cases, surgical-staff car, pharmacy-car, four cars for lying-down cases, kitchen and mess-room car, and stores-car. The train had capacity for 162 lying-down cases and 280 sitting-up cases; total of 442 with a staff of 42 persons. The cars were painted khaki color with Red Cross emblems. The cars for lying-down cases were 54 feet long, open end to end, with 36 beds on brackets in tiers of three, and a lavatory at one end. By folding back the middle tier and arranging the mattresses on the bottom tier to form cushions, the car could be used for sitting-up cases. All the beds could be folded back against the sides for cleaning the cars. The train was provided with steam-heat, electric light and electric fans. The interior was white, with linoleum floors, all corners rounded, and the lavatory floors covered with lead and provided with drain-holes for flushing.[1]

Bath-trains have also been provided, made up of a refrigerator-car for sterilizing purposes, with steam and hot water from the locomotive; two cars with thirty tubs each; two tank-cars for water; one car for undressing; four with clean linen; three for disinfecting clothing and one for the train-crew. In such a train, provision was made for 1200 shower-baths in ten hours.

Railway Experience in the Russo-Japanese War

The Russo-Japanese War of 1904–1905 was remarkable as being waged between forces dependent for lines of communication on the one hand solely by sea, and on the other by land. The Japanese had direct and speedy access across the adjacent seas to the field of action. The Russians labored under the serious disadvantage of relying solely upon a single line of railway over 5000 miles in length from their permanent base of supplies, which was virtually at Moscow. This railway was a single-track line of light construction through Siberia, with heavy grades and sharp curves, laid with rails of 42-pound and 47-pound sections, with sidings eight to ten miles apart and so inadequately equipped and operated that the service was limited to three trains of sixty axles each, daily, in each direction.

Nor was this line continuous. In Farther Siberia, it was broken by a ferriage of twenty-five miles across Lake Baikal, which was frozen to a thickness of four and a half feet between December and May. At the outbreak of the war, in February, 1904, the only communication at this point was by foot or by sledges, supplemented by a temporary railway laid on the ice for the transportation of supplies by animal traction. The temperature ranged to 22 degrees below zero, Fahrenheit, with frequent fogs and heavy storms. During the open season, troops crossed in passen-

[1] Railway Age Gazette.

ger-boats. There were also two steam-ferries, each carrying twenty-five freight-cars and making three round trips daily. But these freight-boats were also used as ice-breakers for the passenger-boats in the earlier and later periods of the winter. This obstruction to communication was only to be obviated by a detour around the southern end of Lake Baikal, where the cliffs rose 4600 feet above the water-level. This 160 miles of line required the construction of 34 tunnels of a total length of six miles, and of 200 bridges, with many large culverts and heavy earthwork. One hundred and twelve miles of this detour were unfinished at the beginning of the War, and it was not opened for traffic until September, 1904.

Other difficulties were encountered in maintaining communication on this long line of railway. Toward the Pacific coast, the supply of water was affected by the freezing up of springs and streams in winter; and in Western Siberia by mineral salts in the water. At first, it was only possible to operate from the European border a daily service of three troop or supply trains, a mail-train and an ambulance-train, on an average schedule of seven miles an hour. The transfer of troops from Warsaw to Mukden required forty days, including a day's rest in every seven hundred miles. For three months after the beginning of the War, the Russian army was without reinforcements; and only at the end of seven months had it received three army-corps. From May to October, 1904, but 21,000 men had replaced 100,000 killed or incapacitated.

Throughout the War, the Russians were hampered by lack of an organization which could prevent military interference with railway operation. The usual congestion of traffic from indiscriminate shipment of supplies to the front added to the embarrassment from this cause.[1] In Manchuria, in September, 1904, reinforcements urgently demanded, took seven days to be transported 337 miles. In December, the junction at Harbin was blocked so effectually that train-service was suspended for twelve hours. In January, 1905, after the fall of Port Arthur, reinforcements were delayed for a month by the accumulation of loaded cars along the line. An idea of the interference by individual army officers may be formed from the statement that the chief of the Viceroy's staff used a special train for which the line had to be cleared at unexpected moments and for indefinite periods. When General Alexieff, the Viceroy, escaped from Port Arthur in May, 1904, three trains were requisitioned for his staff and baggage, at the very time General Kuropatkin was appealing to the authorities to get transportation of ammunition for his heavy guns.

At the conclusion of the War on September 5, 1905, the Russian railway facilities had so far improved as to admit of running ten to twelve trains daily each way into Manchuria, and for assembling at the front an army of 1,000,000 men with necessary supplies. When peace was de-

[1] "Water-proofs sent in summer arrived in winter, and fur overcoats when the water-proofs were wanted." — Railway Age Gazette.

clared, the Russian lines of communication were just getting in condition to supply the needs for the continuance of hostilities, and the Japanese were approaching the exhaustion of their financial and industrial resources.

French and German Railway Preparation Previous to the Present War

In the warfare in which the nations are at present involved, railways are being utilized on a hitherto unprecedented scale. Preparations in this respect were inaugurated by the autocratic government which has controlled the German Empire since its consolidation at the close of the War of 1870–1871. As early as 1896, Joesten, in a work on the use of railways in warfare, boasted that, "Altogether, we have nineteen points at which our railways cross the Rhine, and sixteen double-track lines for the transport of our troops from east to west, as against the nine which were alone available for concentration in 1870." By the end of 1907, the normal tracks in Germany constituted more than one-sixth of the whole railway mileage in Europe, being only exceeded in Russia. The military use of this railway system was facilitated by extensive additions to the station-accommodations at important points for concentration and on the borders of the Empire, by the conversion of single-track into double-track, and by the construction of entirely new lines, ostensibly for commercial purposes, but really as strategic lines of communication.

Such a railway was built from the vicinity of Aix-la-Chapelle to a point on the border at which it formed an additional connection with the railway systems of Luxemburg and of Belgium. At first it was a single-track, but in 1908 it was suddenly converted into a double-track line, with frequent sidings capable of accommodating trains containing an entire army-corps. The Belgian Government was even persuaded to assist in the extension of this line to a junction which afforded a more direct route to Brussels, to Liége and to Northern France; which was only opened for traffic in October, 1913. A branch was built from this line toward the Rhine which afforded a third independent route to the Belgian frontier. This combination of railways was the main line of communication into Belgium at the time of its invasion in 1914.

The lack of a military railway organization in France, which had been so shamefully evident in the preparations for the War of 1870–1871 (see page 418), was taken in hand in a thoroughgoing and intelligent manner, after the establishment of the Republic. Although German methods were originally followed, the system was subsequently modified to profit by the experience gained in other fields of warfare, so as to avoid congestion of traffic at the front, and to provide for a more thorough coördination of the military and technical elements in the control of railway operation.

In 1872, there was created a Superior Military Commission of twelve members, representing the Ministry of Public Works, the Army, the Navy and the principal railway companies. Upon the recommendation of this Commission, seventeen successive legislative and administrative regulations had been announced up to 1883, dealing with military railway organization and transportation. These regulations were amended in 1884, in 1888, and in 1889. Under these amendments, the Superior Military Commission, presided over by the Chief of the General Staff, was to consist of six military officers of high rank, three representatives of the Ministry of Public Works and representatives of the great railway systems.

This Commission was to act in an advisory capacity to the Minister of War, by whom its members were nominated. He was to submit questions for their consideration as to the military use of railways, with respect to —

1. Preparations for military transportation;
2. Examinations of projects for new lines, for junctions or alterations in existing lines, and in railway station-facilities;
3. The arrangement of rolling-stock to meet military requirements;
4. Instructions as to the transportation of troops by rail;
5. Agreements between the War Department and the railway companies as to military transportation;
6. Organization, instruction and employment of special corps of railway men for repairs, etc.;
7. Measures for the protection of railways;
8. Means for destroying and for rapidly repairing railway lines.

The regulation of December 8, 1913, on Military Transport by Railway, further amended "the conditions under which the railways would be operated on the lines of communication," and the arrangements relating to "the organization and carrying out of transport for mobilization, concentration, revictualling and evacuation" in time of war.

In March, 1875, there had been created Field Railway Sections and Railway Troops, for constructing, repairing, destroying and operating railways in time of war. In February, 1889, the Field Railway Sections were constituted a permanent military corps, to be recruited from railway employees. In time of peace, this corps was to be organized in nine sections, each designated by a number indicating the railway system from which it was recruited. In 1906, a tenth section was formed from employees of local lines and tramways to assist in the operation of such lines for military transportation in time of war. In time of peace, these sections were to be subject to inspection and review, as ordered by the Minister of War. Each section was composed of a central body and of three active divisions for movement, traction and roadway, and with three reserve divisions territorially subdivided, but attached directly to the central body. The total strength of each section was 1466 men, including 141 allotted to the central body. An administrative council, composed of the president and heads of divisions of the section, was to meet quarterly in time of peace, and weekly in time of war. Authority over the several sections was to be exercised by the Field Commission to which they were respectively attached.

The Railway Troops, as organized in July, 1899, constituted a regiment of three battalions, each of four companies, recruited from soldiers with previous railway experience and by an annual contingent, not to exceed 240 men, to be selected by the Minister of War from lists supplied in definite proportions by six railway managements. These managements were also to provide a stated number of their officials to form a reserve for the regiment of commissioned and non-commissioned officers.

French System of Military Railway Organization and Operation

In 1912, a systematic course of instruction was arranged for qualifying the Railroad Troops to undertake, in time of war, the destruction and repair of military lines and their provisional operation. The technical instruction comprised that given to the whole of the troops, instruction in particular branches of railway work to a limited number of men, instruction to groups operating in common, and instruction in ordinary railway operation. By arrangement with the railway managements, certain companies were detailed annually to the railway systems for periods of two to three months, to be employed upon repairs or construction on the lines. There was also a Railway School, which drew up programmes of practical work, and had charge of the material and tools used in technical instruction and of construction material for use in war, with workshops for instruction in railway repairs, and practice-grounds for Railway Troops.

Connected with each of the great railway systems there is a permanent Line Commission, consisting of a technical member, usually the General Manager, and a military member from the General Staff. Each Commission has a combined technical and military staff. The duties to be discharged by a Line Commission in time of peace are —

1. Investigation of matters affecting military transportation on the railway system;
2. Study of the available resources of the system to meet military requirements;
3. Preparation of plans, estimates and other data in connection with troop-movements, etc.;
4. Verification of reports concerning the extent of lines, quantity and condition of rolling-stock and of station-facilities;
5. Special instruction of the railway staff;
6. Inspection of lines, bridges, etc.;
7. Experiments for improving or increasing the facilities with respect to military transportation.

The members of the Line Commission are also members of the Superior Commission. As District Executives, they have a number of Sub-line

Commissions, also composed of a military and a technical member and, at very important stations, there is a Station Commission, similarly composed.

Upon mobilization, the Superior Commission is stationed at the War Office, and the subordinate commissions at their allotted posts. The railway systems then become lines for "Strategic Transport," and can be used for ordinary traffic only as approved by the Minister of War. They are further classified in the "Zone of the Interior" and the "Zone of the Armies," the former remaining under the control of the Minister of War and the latter being transferred to the Commander-in-Chief. The two zones are connected at "Stations of Transition." The Zone of the Interior is subject to military control for the forwarding of troops and supplies, as ordered by the Minister of War and regulated by the Chief of the General Staff. Such orders are executed by each Line Commission in its particular territory. The Zone of the Armies is divided into two sections: the "Front Zone," in which railway operations are conducted strictly under military control, and the "Rear Zone," in which operations may still be conducted by the ordinary railway staff under the direction of a Line Commission.

Transportation in the Zone of the Armies is controlled by the "Director of the Rear," who is stationed at the headquarters of the Commander-in-Chief, and keeps in touch with the Minister of War through the Chief of the General Staff. It is his special function to secure coördination between the services in the two zones and to see that the needs of the army as to transportation are satisfied in accordance with their respective degrees of urgency. He maintains an exchange of information as to time-tables for military trains, and similar details. He has, also, supervision of the service on the highways, but is not responsible for the actual working of either the railway or the road service.

Within the Zone of the Armies, the service is actually controlled by a Director of Railways, assisted by a combined military and technical staff, by a Line Commission in the section operated by the ordinary railway staff, and by Field Commissions and Railway Troops in the section under military operation. The Director of Railways manages the coordination of the service at the Stations of Transition, and decides as to the distribution of rolling-stock and the railway personnel within his own zone, in which he also controls the road-service.

The Field Line Commissions are the executive agents of the Director of Railways, each being composed of a staff officer as chief and a technical assistant. Each Commission has under its command a body of Railway Troops, a telegraph staff, Station Commissions and a gendarmerie for policing the stations and trains. The Commission also carries out the work of construction, repair, maintenance and destruction on the lines under its control.

For the conveyance of troops, there are Mobilization and Junction Stations, whence the men in a certain district are sent to the Embarkation Station, for concentration in complete units. Then follow "Stations for Meals" for men and horses and, at the end of the route, come the Detraining Stations. As regards supplies, they are collected in each specified district at a Base Supply Station for a certain army-corps. Here they are made up in train-loads, or otherwise, to facilitate their further transportation. In certain cases, supplies in train-loads may be shipped directly to their ultimate destination, but usually they are consigned to Supply Depots, from which they can be forwarded as required. These Supply Depots are differently organized to meet the requirements of the several branches of the service. On the outbreak of war, those in the Zone of the Armies pass under the control of the Commander-in-Chief.

Before the opening of the War in 1914, there had been concentrated at ten railway centers reserve supplies of 707,000,000 rations. At present, there are 20 central stations within 50 to 60 miles from the front, each of which provides daily supplies for from 50,000 to 100,000 men. The commissary officers at these stations forward daily from 40 to 120 car-loads of supplies for each army-corps to a regulating station, where the trains are broken up and the supplies classified and sent forward to the distributing stations, from four to ten miles from the front. From these points, cars are started and dropped off as required.

Each Station Depot is under the charge of the Chief of the Station Commission, who fills the orders as received. He gives instructions as to the time when the supplies are to be loaded and ready for departure, but does not otherwise interfere with the railway operations. He is also responsible for the immediate unloading of supplies at the Station Depot. From these Supply Depots, shipments pass to the Regulating Station, which is in immediate proximity to the fighting line, and may be frequently and unexpectedly changed, according to the military situation. It is in charge of a Regulating Commission, which is responsible for the supply of stores, as to their nature and the quantities required at the front, and for the prompt delivery of them as demanded at the rail-head, which is the point of connection with the road-service in the immediate field of warfare. These arrangements are equally applicable for transportation, in the opposite direction, of the sick and wounded, of prisoners and of supplies. For dealing with the sick and wounded, there are Evacuating Stations, either at the rail-head or at the regulating station; also Infirmary Stations along the line of communications, where patients can receive needed attention. From the Distributing Stations, they are sent to the hospitals to which they may be assigned.

The French system of organization has been commended by military experts, and even by the Germans, as regards troop-movements. In a test in 1887, 150 military trains were dispatched from Toulouse, without accident or interruption to the ordinary traffic. In September, 1892, 42 trains were sent from an improvised station in eight hours, with a complete army-corps of 25,000 men.

German and French Railway Operation at the Beginning of the World War

At the outbreak of the great war in 1914, the German railway system was fully prepared, with resources collected and operations planned during the forty-three years that had elapsed since the Franco-Prussian War. Its direct lines of communication were connected intermediately like a cobweb. Many of these were purely strategic, designed for quick concentration and speedy movement between the French and the Russian borders. These lines had been thoroughly reinspected and provided with ample station-facilities. A time-table for military trains had been supplied to commanding officers throughout the Empire. At the word of command in August, 1914, this whole system was at once set in motion, like any other part of the military organization.

Four million men had been called to arms, and were to be transported to the field of action with the supplies necessary in time of warfare. There were also 800,000 horses to be transported and fed. For this movement, there were twelve double-track lines from the interior of the Empire that reached the Rhine for one hundred and twenty-five miles along its banks, and were connected by eighteen bridges across that river with the strategic lines to the French and Belgian frontiers. Each army-corps, normally garrisoned in a district, had a double-track line at its disposal, and eight to ten cavalry divisions could be moved simultaneously with the army-corps. Four brigades with their cavalry and artillery contingents required ninety-six trains, and all of these trains could be dispatched in the same direction within twelve hours. The movement of fifty-eight army-corps to the western frontier, in August, 1914, was accomplished between August 3d, P.M. and August 4th, noon, and Liége was assaulted on August 5th.

The French lines of communication radiated from Paris to the German frontier. But, relying upon the recognition by Germany of the neutrality of Belgium, no adequate provision had been made for reaching the Belgian frontier. Nor did the French railway system provide for the unanticipated movement of British troops from the Channel ports to that front, for which purpose some 4200 miles of standard and narrow-gauge lines were subsequently constructed up to the Spring of 1917. There was but one line of communication to Verdun, which is the outer bastion on the German border, and this line was in easy reach of the German guns. A narrow-gauge branch-line along the Meuse gave another and more circuitous route via Bar-le-Duc, but that was cut by the Germans near St. Mihiel in October,

1914. This key to the defense of Paris has therefore been mainly dependent upon motor-trucks for the transportation of supplies.[1] On the French railways between August 1 and 20, 1914, 1,800,000 men were taken to the front, most of them having been transferred three times. About 10,000 trains were in continuous operation.

Railway Operations in Great Britain and Italy

In Great Britain, the Government assumed control of the railway system on August 14, 1914, under the provisions of the Railway Act of 1871, and operated them through the Railway Executive Committee.[2] The military authorities notified this Committee when a movement was to be made, and the hour at which the troops should be at the point for embarkation. On forty-eight hours' notice, 350 trains, averaging 30 cars each, were ready for service and, within a fortnight, the Expeditionary Force had been landed in France. For three weeks, 73 trains per day were sent into Southampton Docks at intervals of 12 minutes, and the guns, ammunition and horses were unloaded at ship's side. This was accomplished with but little interference with the general traffic.[3] Up to February, 1915, there had been 15,000 military trains over the London & Southwestern Railway.

In Italy, as in France, the railway system was divided for military operations into a "War Zone," covering the fighting line, and a "Basic Zone," which covered the remaining territory. All troop or supply movements originating at the ports or in the interior are directed to some station of transition on the frontier of the War Zone. After delivery there, the further railway operation is conducted entirely under military direction by the railway organization within the war zone. This frontier extends from the French border through Alessandria, Piacenza and Bologna to the Adriatic Sea. The basic zone is in eleven subdivisions, and the war zone in three, which branch out from Bologna, the principal station of transition. In each of these three subdivisions, the trains cross the valley of the Po to the secondary transportation systems in the mountains, on a front of 450 miles. In the war zone, with 2448 miles of line, there have been built, in eighteen months, 180 miles of standard-gauge line and 120 miles of narrow-gauge. Five hundred and ten miles of line and 18 bridges have been built or rebuilt.

The control of the basic zone centers in Rome, where calls are made for transportation to the war zone. The authority over military traffic remains with the basic organization until its delivery to the war zone organization at stations of transition. Certain train-equipment is specially set apart for this service, which may be used for commercial purposes on

[1] See Railway Age Gazette, May 22, 1917. [2] See page 420.

[3] "British Railways in War-time." H. R. Wilson.—Railway Review, Chicago, April 21, 1917.

its return trips. There is military inspection at important stations and junctions. At the entrance of Italy into the war, the Government had at its disposal 5000 locomotives and 160,000 cars. On two lines, 120 trains were daily in service. Between May 17 and June 22, 1916, they handled 540,000 men, 70,000 animals, 16,000 vehicles and 900 guns.[1]

Light Railway Construction and Operation in France

Not less than five thousand miles of light railway have been built on the French battle-front. They are laid with 20-pound rails and pressed-steel ties in sections of about four, eight and sixteen feet, and weighing respectively three, five and eight tons. The gauge is usually 60 centimeters, or about two feet.[2] Almost the first work done by a Canadian railway battalion in France was to build 2000 feet of light railway in full view of the enemy, working only at night. By midnight of the second night, a train passed over it. The next day, an observation balloon dropped two hundred bombs on the line, breaking one rail, which was replaced in a few minutes. In following up von Kluck's retreat from the Marne, eleven miles of standard track were rebuilt in fourteen days, and five days afterward the line was supplying 80,000 men. On this occasion, wrecked German motor-cars were used in the foundation for a fill. While the battalion was under fire, the German narrow-gauge track was picked up in sections and thrown aside, the men wearing steel helmets with gas-masks at hand. Bridges had been blown up, the road-bed obliterated and occasional mine-traps were encountered. Under these conditions, 4¾ miles of road were rebuilt in five days, including a bridge 140 feet in length. In this work. the railway battalions were reinforced by four brigades from the British army.[3]

The use of heavy guns in the trenches has been made practicable by the construction of these light railways; not only for placing them in position, but also for withdrawing them, in case the trench-lines were broken by the enemy. Formerly, a five-ton gun was the heaviest used for field-operations. Now, there are thousands from 30 to 50 tons in weight and many from 50 to 75 tons. For instance, in a battered drinking-shop, a telephone-connection was established with the track-material station. Two thousand yards of narrow-gauge line were staked out, and, as the rails were being laid, a twelve-inch howitzer followed on them. As it approached its position, the gunner telephoned to have his range corrected for it, a hundred men being at the time engaged in moving the gun on

[1] Railway Age Gazette, January 12, 1917.

[2] For construction and operation of such railways, see "Military Railways." Major W. D. Connor. "Professional Papers, No. 32." Corps of Engineers, U. S. Army.

[3] A statement of a month's work of one of the Canadian railway battalions is given in Appendix VIII, Note V.

the track over a yawning crater, while the German shells were bursting overhead.

Field Marshal Haig said that each locomotive on these light railways was worth a battery of field-guns. On the French front, the locomotives are of the "Pechot" type,[1] designed in 1888 for use in the Morocco campaign. Two hundred and eighty of these locomotives for the 60 centimeter gauge have been built by the Baldwin Locomotive Works to meter measurements. They are carried on two steam-driven trucks or bogies (0–4–4–0), each with two cylinders, and under a single control. The boiler has a smoke-box at each end. It is fired intermediately with independent fire-boxes and tubes, but with a common outside shell and large steam-space. The weight is transferred to the center-pins through heavy rubber rings, and the side-bearings are of rubber to give flexibility. A large number of men can be carried on the running-boards. The Baldwin Locomotive Works has also furnished "fireless" locomotives,[2] for use where the fire hazard is great, which will run 6.2 miles on one charge of the reservoir and will haul 80 tons up a 0.4 per cent. grade.

Special Railway Equipment for Heavy Gun Transport

The increased weight of modern artillery has also required specially constructed railway equipment for its transportation, and particularly for the guns employed in coast-defense. The larger the gun, the shorter is its life, when measured by the number of rounds fired from it. A twelve-inch gun has been fired thirty rounds at the rate of two rounds per minute. In a protracted engagement, from eight to ten guns per day are required to give the continuous service of one; and the removal of the exhausted gun and the placing of a substitute must go on at the rate of one for every three hours.

Ninety per cent. of our munition works are within one hundred and sixty miles of New York City, 1600 miles from the Rio Grande and 2500 miles from the Pacific coast. For transportation between each point of action and the gun-factory, special provision must be made; so that the efficiency of every fortification depends upon its facilities in this respect. In May, 1916, there was but one car in the United States that could carry the new 16-inch gun. The 14-inch gun can be transported on a 200,000-

[1] Pechot type. Fuel, soft coal. Cylinders, 6.45 inches by 9.45 inches. Boiler pressure, 170 pounds. Driving-wheels, 25.6 inches in diameter. Wheel-base, 12.5 feet. Rigid base, 35 feet 4 inches. Weight, 28,100 pounds. Copper fire-box, brass tubes, saddle-tank.

[2] Fireless locomotive. Standard gauge. Cylinders, 15 inches by 16 inches. Driving-wheels, 30 inches in diameter. Wheel-base, 5 feet 6 inches. Weight, 42,750 pounds. Receiver holds 208 cubic feet of water with 52 cubic feet of steam-space. Storage-pressure, 170.6 pounds, reduced to cylinder-pressure of 50 pounds. Steam- and hand-brakes. Storage-battery for electric headlights. — Railway Age Gazette, May 22, 1917.

pound flat car, with an ordinary flat car as a trailer, though there are but few flat cars of 100 tons' capacity.[1]

The use of heavy guns in trench-warfare would be impracticable without railway transportation. Formerly, the body of the gun was dismounted and placed on a separate car. Now, the 20-inch gun is loaded on a single flat car with an intermediate supporting truck. Guns of 30 to 40 tons are carried on two cars fastened together and bearing an overhead steel platform, on which the gun rests on the gun-truck; 50-ton guns are handled on specially constructed all-steel cars. The pieces are usually placed in position at night by building a permanent track right up to the emplacement. After the revolving table has been prepared, the gun is slid into position upon strong hand-cars.

It is interesting to note the gradual extension of railway service toward the battle-front, from the standard track for general purposes to the light railway within the war zone and to the 60-centimeter gauge on the immediate firing line, while the caterpillar-tractor or "tank," which carries its own track on its back, is but a further projection of railway transportation into the field of offensive warfare.

Railway Efficiency in Warfare

The efficiency of railways in warfare has been restricted by the apparent incapacity of the military authorities to recognize the most practical ways of turning them to account in providing their facilities at the times and places where they may be required. Their operation should be left with those who are familiar with their use; otherwise their efficiency will be diminished by conflict of authority. Railway operation is as much a technical service as are military operations. A railway system is a complicated instrumentality, of which the personnel is an essential part. Not only are experience and technical knowledge required, but also acquaintance with the environment and characteristic features of each railway line. The fundamental principles for the successful operation of railways in war-time, are the unification of control and the coördination of the military and the technical elements in the controlling body.

[1] Weight and Dimensions of Guns for Coast Defense

Caliber	Weight	Length	Width
	Pounds	Feet	Inches
12-inch	132,000	42.0	66.2
14-inch	139,000	48.25	66.7
16-inch	284,000	49.25	90.5
16-inch (new)	367,000	67.17	88.0

"Railways in a System of National Defense." W. L. Park. — Railway Age Gazette, May 26, 1916.

Experience has proved that a special method of railway operation should be applied in the vicinity of military operations. With this in mind, the French Government divided the field of operations into the basic zone and the war zone, the latter being delimited from time to time as indicated by military exigencies. In the basic zone, operations were to be conducted by the usual methods, with due regard to military requirements. Within the war zone, military methods were to prevail. The correctness of this principle has been confirmed by experience. Applying it to our own country, the war zone may be considered as coterminous with our coast-line. The ports on this line should be operated as stations of transition, at which the change of control takes place. The control at these stations should be exercised by a joint commission of army, navy and railway officers.

There is nothing of greater importance in the application of railway transportation to military purposes than the orderly movement of supplies to the front. The fault most to be guarded against is the congestion at the transition-stations caused by the shipment to them of immense quantities of military supplies too far in advance of the provision of adequate facilities for farther carriage. This has invariably taken place at the outbreak of hostilities, and has served to embarrass subsequent military movements for indefinite periods. The trouble arises from multitudinous demands from many independent authorities. The remedy is to direct all such demands to a central authority, empowered to determine their relative importance and to issue orders to the railway officials as to priority of movement. With such an organization on the part of the government, the congestion of traffic would be greatly diminished.

An idea may be formed of the magnitude of the railway service required in the present war from the statement that, to maintain the necessary food-supplies alone for an army of 4,000,000 men on a line of 600 miles long by 20 miles broad, there is required a daily shipment of 25,000 tons.[1] The supply of ammunition to be provided, in these days of quick-firing heavy artillery, is enormous. The total consumption of shells in the attack and defense of Verdun in thirty weeks was estimated at 60,000,000, equal to 3,000,000 tons of steel. During the month of September, 1917, 500 trains of 25,000 cars of ten-ton capacity were required to keep the French lines supplied with ammunition. Sherman, in his march through Georgia, carried 60 guns and 200 rounds of ammunition per gun. The total expenditure by 310 Federal guns in the three days' fight at Gettysburg would last for about seven rounds for the same number of modern guns. A single mile of completely entrenched line may require 1000 miles of barbed wire, 1,000,000 running-feet of lumber and 6,000,000 sand bags.

The transportation of troops is a simpler matter, as the men can be

[1] On the Italian front, 38 locomotives with 1400 cars hauled monthly for three months, an average per month of 144,000 tons of war material.

entrained or detrained under military discipline, and the amount of equipment required for the respective military units can be previously determined with accuracy. To move a field-army of 80,000 men requires 6229 cars in 366 trains of 2115 passenger-cars, 385 baggage-cars, 1055 box cars, 1899 stock-cars and 775 flat cars, with 100 train-loads of munitions and supplies. This equipment represents 0.7 per cent. of the number of locomotives on our entire railway system, 4.2 per cent. of the passenger-cars and 0.2 per cent. of the freight-cars.[1]

Conclusions as to the Value of Railways in Warfare

From experience in the use of railways in war-time, certain conclusions may be drawn. The more general one is that railway transportation has enabled warfare to be conducted on a more extensive scale than would otherwise be possible.[2] The barbarian hordes from the Sarmatian plains that overwhelmed the Roman Empire moved, *en masse*, with the means of transportation which were in daily use, and to which their movements conformed. The manner in which the invasion of Hellas by Xerxes was conducted and the length of time required for its preparation have already been described. There could have been no element of surprise in a campaign of this character. For this reason, in the classic examples of successful invasion, the armies were commensurate with the available means of transport for supplies, and the rate of advance was limited by the average length of the daily march.

Alexander began his conquest of the Persian Empire with 30,000 infantry and 4000 cavalry. Hannibal is said to have crossed the Alps with 90,000 foot, 12,000 horse and 37 elephants. Caesar's largest army in the Gallic Wars consisted of 80,000 foot and 25,000 horse. In the Battle of Waterloo, 72,000 French troops were opposed to 67,000 British and Dutch allies, until Blücher turned the scale with 50,000 Prussians. Napoleon mustered 600,000 men for his Russian campaign yet, with but one important battle, in which he lost 20,000 men, he recrossed the frontier with but 12,000. These examples indicate the practical limit to an invading army as long as the rate of advance was restricted by the marching capacity of man and horse, and the available transportation by beasts of burden and draft. Compare these examples with the invasion of Belgium in 1914, when 58 army-corps, with all necessary supplies, were concentrated on the western border of the German Empire in thirty-six hours from distances as great as four hundred miles! Great indeed is the revolution in the strategy of warfare that has resulted from the use of the railway in

[1] Railway Age Gazette, August 17, 1917. For equipment required in mobilization of military units, see Appendix VIII, Note VI.

[2] "The battle of the Marne was won by the railroads. Without the railroads, it would never have been possible to bring up the supplies, to provide the armies with munitions, and all the things necessary to carry on the battle."—Marshal Joffre.

military operations. It has rendered possible the concentration of men in overwhelming numbers and of supplies in enormous quantities from an area which is limited only by the extent of the railway system, and to maintain such armies in efficiency by promptly replacing the wastage of both.[1]

With the strategic railway system of Germany, the same armies have been employed alternately on its French and on its Russian frontiers, which are nearly a thousand miles apart. For this purpose there were available six double-track lines, over which military trains were moved at the rate of 250 miles in twenty-four hours. For six army-corps of 40,000 men each, a week was allowed, with two to three days for preparation. The break of gauge at the national frontier had been adopted by the Russian Government, as a strategic means of defense, at the inception of its railway system, by establishing its gauge at five feet. The futility of this plan was shown in the German invasion, when the rails on one side of the line were closed up to the standard gauge as rapidly as the army advanced. With a narrow-gauge line, the gauge could not have been so easily changed, by reason of the shorter length of the cross-ties.

The value of railway transportation in warfare is, of course, diminished by obstructing the track or by its destruction. In Europe, some of the more important railway bridges are protected in time of peace by permanent fortifications, and in time of war by block-houses. In the South African War, the lines of communication within the war zone were protected at distances of 2000 yards by block-houses surrounded by wire entanglements and connected by alarm appliances. Every bridge over thirty feet span was guarded by an entrenched post.[2] These military measures are supplemented by an organized force of experienced railway men for the speedy repair of track. This force is also employed in the construction of light railways at the immediate battle-front. Such railways are also operated by these "railroad regiments" under military discipline and commanded by railway officials with military rank.[3]

American Experience in Civil and Spanish Wars and on Mexican Border

By Act of Congress, January 31, 1862, the President of the United States was authorized to take possession of all the railroads in the country, and a general order to this effect was issued, May 25, giving precedence to the transportation of troops and of munitions of war. Quartermaster General Meigs, in his annual report for 1865, stated that this service "has been performed so zealously and satisfactorily by the railroads of the loyal

[1] The wastage of an army in marching is a serious matter. German military authorities estimate the "falling-out" at three per cent. in cool weather, and at six per cent. in hot or wet weather.

[2] "Rise of Rail Power." Pratt, p. 58.

[3] The organization of railroad regiments is described in Appendix VIII, Note III.

states, that it has not become necessary since the passage of this law actually to put this military authority into exercise over any road not within the limits of an insurgent State." Col. L. B. Parsons, Chief of Rail and River Transportation, in a report dated October 15, 1865, in an extended commendation of the assistance rendered by railroad officials and employees, said, "The earnest efforts of those controlling the different lines of railroads have been most conspicuous. It is to this class of men that the government is largely indebted for many of its brilliant triumphs."

With the close of the Civil War, our military strategists apparently gave no farther thought to the application of railway operations to warfare. If they did, the results are secreted in the archives of the War Department. Certainly they showed no disposition to collaboration on the subject with railroad officials, notwithstanding the commendation of them from the office of the Quartermaster General. In a work of 500 pages on "The Military Policy of the United States," written in 1881 by General Upton, the only reference to the value of railways in warfare is contained in the following sentence: "It was early discovered that railroads, as lines of communication, have exercised a powerful influence over military operations and that to insure the regular transportation of troops and supplies those at least within the insurrectionary States must be under the control of the military authorities." Yet General Upton had held important commands in the Civil War and had subsequently made an official visit to the headquarters of the European armies.

In the preparation for the War with Spain in 1897–1898, military transportation was conducted as in time of peace. Troops were moved without system and the arrangement of trains, the routeing and the organization for entraining and detraining were left to the discretion of railroad employees with little previous training for such operations, who were further embarrassed by military officers with none at all. Past experience as to the congestion of traffic due to the indiscriminate and premature forwarding of supplies by separate departments was again repeated. The only concentration point for the campaign in Cuba was at Tampa, where two rival lines converged. Trains were there made over, and the contents of many cars were transferred for forwarding nine miles farther over a single track to the port of embarkation at Port Tampa. The station-facilities were altogether insufficient, but no request had been made for their enlargement in anticipation of such an accumulation of traffic. The sidings at both places, and farther back on the lines of communication, were blocked with cars whose contents could only be ascertained by a search through huge piles of way-bills.

In a report by the General Staff "On the Organization of the Land Forces of the United States," published August 10, 1912, and commended by the Secretary of War as containing "the broad outlines of a comprehensive military policy," a scheme is proposed for "A Council of National Defense." This Council was to be composed of the President of the United States, three members of his Cabinet, eight chairmen of Congressional Committees, the Chief of the General Staff, an officer of the Navy and the Presidents of the Army and of the Navy colleges. There is not one word in sixty-four printed pages as to the relations of our railway system to military transportation.

In May, 1916, the Quartermaster General issued a "Handbook of Transportation by Rail and Commercial Vessels," containing over five hundred paragraphs on the subject. In the ninety-six relating to train movements by rail, there are three references to the existence of an operating railroad official. One of these requires the presence of a quartermaster at the loading of trains to examine the train and its equipment and "to adjust matters in case of controversy between the agents of the railroad and the commanding officer." Another requires the quartermaster to "detail a competent enlisted man or employee to act as a yardmaster, — to keep the shipping quartermaster generally informed as to progress of loading so that he can take prompt steps to prevent any unusual delay." In the third reference, when any unusual delay to a train-movement continues after a reasonable time has elapsed, the commanding officer "should communicate by wire with the division superintendent."

Coöperation of American Railway Association in Troop Mobilization

Soon after the issue of the Quartermaster General's Handbook, there was a call for the mobilization of troops for service on the Mexican border. To facilitate this movement, the Executive Committee of the American Railway Association appointed a Special Committee on Coöperation with the Military Authorities. By invitation of the Quartermaster General, this Committee met in conference with his representative, Lieut. Col. C. B. Baker. Arrangements were made for placing a railroad representative at each department headquarters, at each mobilization camp and in the office of the Quartermaster General, who were to act as advisers on matters affecting railroad transportation.

The value of this plan for coöperation was demonstrated in the mobilization and concentration of the Organized Militia. The militia troops began moving from the camps about midnight of June 26, 1916. On July 1, there were *en route* 122 trains of over 2000 cars, carrying 36,042 men; and up to July 31, 111,919 militia troops had been transported to the border. Over 3000 passenger-cars, including standard Pullmans, tourist-sleepers and coaches were employed in this movement; and in addition, 400 baggage-cars, most of which were equipped for serving hot meals, 1300 box-cars, 2000 stock-cars and 800 flat cars. The distances involved in this movement varied from 608 to 2916 miles, while the longest run in the German Empire does not exceed 700 miles. There was but a single accident, of a minor character. Considering these great distances, "the celerity with which the trains were moved, and the entire absence of congestion or delay, it is believed that there has been no case in history where troops have been as well and as safely transported, or as well cared for while *en route*."[1]

Through the agency of the American Railway Association, cars placarded as containing army-property were given precedence, and shipments were made with remarkable expedition. Many instances were cited of shipments from Washington to the border in four days and from New York in five days. "The hearty coöperation of the railroads in making these shipments has been rendered without any hesitation whatever, with all the energy possible, and without any additional charge to the Government."[2] In a report from the Secretary of War, it was stated that, "The disturbed condition on the Mexican border in consequence of the Columbus raid gave us an actual experiment in the use of our railroads, the readiness with which their facilities could be organized in the service of the Government, and a most instructive and helpful demonstration of the hearty coöperation which the Government can expect from those who manage these great transportation enterprises."

President Wilson wrote to the President of the American Railway Association as follows: "The Secretary of War has just called my attention to the arrangements made by the American Railway Association for coöperation by the railroads of the country with the Quartermaster General and the Quartermaster's Corps, and to place at the service of the government for military purposes the railroads of the country in the emergency created by the call to arms of the National Guard.

"I beg to express to your association my appreciation of the effectiveness of this coöperation and of the patriotic impulse which led to its spontaneous suggestion by the American Railway Association."

The appreciation in the Quartermaster's Corps of the value of railway experience in military transportation appears in a private publication on "Coördination Between the Transportation Companies and the Military Service," by Lieut. Col. Chauncey B. Baker, in which reference is made to "the difficulties that have arisen in the past with us in procuring the fullest coöperation between the railway and military authorities." In this pamphlet it was proposed to organize a Military Transportation Commission of executive officers of the railway companies to assist the Quartermaster's Corps "in reaching conclusions in regard to matters of rail-transportation"; the members of the Commission to be nominated by the American Railway Association. In addition to this Commission, it was suggested that there should be sub-commissions covering locally the same matters, and that committees of officials from the several railway

[1] Report of the Quartermaster General. [2] *Ibid.*

departments should be appointed by the Commission to confer with the Quartermaster's Corps regarding matters affecting their particular branches of the service. "It is believed that the Commission here proposed could operate effectively and intelligently, and accomplish satisfactory results by coördination with the Transportation Division of the Quartermaster General's office."

The United States entered upon the European War at a time when its railway system was already taxed beyond its ability to provide for the current traffic. This condition of affairs was the outcome of the insensate policy of unrestricted competition. The efforts of the railroad managements to restrict competition within reasonable limits had been defeated by the Federal and the State governments. Yet the legislation intended to preserve unrestricted competition had resulted in a rigid system of rate-making which had put an end to all competition, except that which could be carried on by subterfuge.

It had restricted earnings as well as competition at a time when, from economic and political causes, the cost of operation had been so greatly increased, and the net revenue proportionately diminished, as to deter the railroad managements from providing adequately for the secular increase of traffic. At the very time when the operating officials were struggling with this situation, an immense addition had been suddenly made to the current traffic by the demands of the warring nations for munitions of war and for food supplies, with the consequent reaction upon railroad operation from the inevitable congestion at seaboard terminals. The railroad managements were further hampered by the regulation of railway operation in matters of detail, which had been fostered by class-legislation. Our railway system was in this critical situation when the declaration of war against Germany, on April 6, 1917, threw an unforeseen burden upon it, for which there had been no adequate preparation.

In anticipation of this crisis, which had been foreshadowed by the rupture of diplomatic relations with Germany, a special meeting of the Executive Committee of the American Railway Association was held on February 16, 1917, at which the following preamble and resolutions were adopted and forwarded to President Wilson:

"Whereas, the President of the United States has appointed a National Council for Defense for the purpose of ascertaining the resources of the country and of securing the coöperation of all organized transportation and industrial activities in furtherance of this purpose;

"*Resolved*, that, in order that the railways may be in a position to assist with their full strength the National Council for Defense, fourteen members be added to the Special Committee on Coöperation with the Military Authorities, including Mr. Fairfax Harrison as General Chairman, so as to constitute a committee of eighteen members, to represent the railways in connection with the work which the National Council for

Defense has in hand; the membership of the Committee to be representative of the four army departments into which the country is divided;

"*Resolved*, that the name of the Special Committee on Coöperation with the Military Authorities be changed to Special Committee on National Defense, of the American Railway Association."

In accordance with these resolutions, the Special Committee on National Defense was organized with six railroad executive officers representing the Eastern Department, five representing the Central Department, three the Southern Department and three the Western Department.

At a conference of railway executives in Washington, April 11, 1917, a set of resolutions was adopted in the form of an agreement for the operation of the railroads of the country as "a continental railway system under the direction of the Special Committee on National Defense of the American Railway Association, and without special consideration or compensation."[1] Under this agreement between 631 railroad companies, the Special Committee on National Defense was reorganized as a General Committee of thirty-six members in sections for the six military territorial departments, each with a chairman. From the General Committee, there was formed an Executive Committee of four members with Fairfax Harrison, President of the Southern Railway Company, as Chairman, and of two members *ex officio*, Daniel Willard, President of the Baltimore & Ohio Railroad Company and a member of the Advisory Commission, Council for National Defense, and E. E. Clark, of the Interstate Commerce Commission.

The Executive Committee, usually known as "The War Board," in the exercise of its functions was to be assisted by subcommittees on Car Service, on Military Equipment Standards, on Military Transportation Accounting, on Military Passenger Tariffs, on Military Freight Tariffs and on Materials and Supplies. Coöperation with the military authorities was provided for by the appointment of General Agents on Transportation and on Accounting at Washington and at the headquarters of the six military departments. Similar General Agents were placed at the mobilization camps for the same purpose. About 340 experienced railroad officials were assigned to these duties.

The Vast Field of American Railway War Operations

In a review of the relation of the railway system to military operations at this period, the continental territory of the United States may be considered as the Zone of the Interior, or the Basic Zone, with the Atlantic coast-line as the border of the War Zone, and the ports along that line as the Stations of Transition, toward which the lines of communication tend. The Basic Zone includes an area of 3,000,000 square miles, covered with a network of 260,000 miles of railway extending from ocean to ocean, and

[1] See Appendix VIII, Note VII.

equipped with 2,500,000 freight-cars, 56,000 passenger-cars and 65,000 locomotives, and manned with 1,750,000 employees. The War Zone is almost limitless, taking in even the oceans themselves as well as Europe.

Never before has railway transportation been applied to military uses on such a field of action. The objects to which immediate attention were to be given were the movement of men to the camps and of supplies to the ports. With the experience gained during the disturbance on the Mexican border, the troop-movements were successfully accomplished. From August 1 to November 27, 1917, the movement to training camps and embarkation points included over 1,500,000 men, of whom 500,000 were transported in overnight-travel in sleeping-cars furnished by the Pullman Car Company. In one instance, 8000 men were transported across the continent for 3700 miles in less than a week. They traveled in sixteen trains, each composed of twelve tourist-sleepers and two baggage-cars. The schedule speed of troop-trains has been fixed at 25 miles an hour, with a reduction to 20 miles an hour when freight-cars are included in the train.

There existed however the congestion of freight-traffic which invariably ensues upon the premature shipment of military supplies to stations of transition on the border of the war zone. This situation had been aggravated by the previous shipments to the Allies and to the needy population of Europe. Yet, in a statement issued by the General Chairman of the Special Committee on National Defense, it was believed that the railroad companies would be able to afford to the Government all the service that it might require, without substantial interference with the commercial business of the country.

On April 13, 1917, at the request of the President, a bill was introduced in the House of Representatives authorizing him to take possession of the railroads and the telegraph and telephone lines, and to place under military control all officers and employees of such lines. As finally passed, on August 6, this measure, known as the "Priority Bill," merely empowered the President to order that preference be given to such commodities as he might deem essential to the national defense. Recognition was given to the maintenance by the railroad companies at Washington of such a committee as the War Board, to carry out the President's orders. The Interstate Commerce Commission was increased from seven to nine members, with authority for its division into sections for administrative work. In all proceedings relating to the reasonableness of rates or to alleged discriminations, not less than three members were to participate, and five members in all valuation hearings. No increases in railroad rates were to become effective before January 1, 1920, without first having been approved by the Commission.

On April 26, the War Board suspended the Car Service Rules for securing the prompt return of freight-cars to their owners and issued "Emergency

Rules" framed to give preference to coal and iron ore. The Board "looked to the President of each road personally to see to it, as a special charge upon the good faith of himself and his railroad, that this rule is not evaded or abused." "If failure occurs, this committee will take prompt and effective steps to correct all such cases by disciplinary measures, including the publication, when deemed necessary, of names of officers and railroads refusing or failing to respond to this appeal."

On May 4, the War Board issued another appeal, suggesting measures for increasing the efficiency of railroad operation, in which it was stated that the capacities of the railroads "are now overtaxed and they are unable to respond promptly to all demands upon them." In hearings before the Federal Trade Commission, it was testified that the railroads were diverting cars from the transportation of coal to that of commodities upon which higher rates were obtainable, and the Commission recommended that the Government should take over the railroad operation to increase the supply of coal and to prevent undue increases in its cost. The War Board responded that in May, 82 principal bituminous-coal carriers had handled 142,157 more car-loads of coal than in May, 1916, being an increase of 7,100,000 tons, or of 15 per cent. In June, there had been a corresponding increase of 26 per cent., and in July, on 132 roads, there had been an increase of 207,429 car-loads, and of 10,316,000 tons, or of 31.5 per cent.

The policy adopted by the War Board for increasing the efficiency of the railways, as a single system, was that of concentrating their transportation-facilities successively in different fields of action and upon different classes of traffic, according to the urgent need for them. The representative associations of the principal industries coöperated heartily in plans for increasing the efficiency of the railroad service by more intensive loading, by concentration of shipments for common points of destination and by pooling such shipment for transshipment from rail- to water-lines. Attention was first given to the movement of coal. On July 23, a plan for pooling coal for export was agreed upon between the Coal Production Committee of the Council for National Defense, the War Board and the Tidewater Coal Exchange. Instead of keeping separate 1156 different kinds of coal for shipment to the seaboard, the grades were reduced to 41, although in making this reduction, long-established trade-names were sacrificed. All coal of the same kind was to be placed on the same tracks for shipment directly into the vessels, instead of having shipments from particular mines switched separately from the classification-yards. Each shipper was to keep a debit and credit balance with the Deputy Commissioner of the Tidewater Coal Exchange at each port. The amount of coal to be controlled from the four coal-exporting ports was estimated at 35,000,000 tons per annum.

By an arrangement between the War Board and the coal-operators, a similar plan was presented to the Council for National Defense for pooling the coal passing through nine lake-ports to the head of the Great Lakes, under an executive committee composed of three representatives of coal-shippers and two of the docking-companies, the railroads being represented by a Special Commissioner. It was estimated that, by this plan, individual shipments would be reduced from 800 to 120, and that the average detention of coal cars at lake ports would be shortened from 3⅗ to 2 days. Vessels would not be held for the accumulation of individual cargoes, and there would be an increase in the return tonnage of ore and other freight.

The measures taken by the War Board had resulted in a continuing decrease of "car-shortage" or of unfilled car-orders which, at the end of April, 1917, had amounted to 148,627 cars, and by the end of June had been reduced to 77,144 cars. The increase in transportation-efficiency was exhibited in a comparison of the statistics for July with those for the entire second quarter of 1917. Locomotive-mileage had increased 6.8 per cent., and car-mileage, 7.2 per cent. The average car-load had increased 11.1 per cent., and the train-load, 10.4 per cent. Roads operating 220,000 miles of line had increased their ton-mileage 20.2 per cent.

To quote the language of Hon. W. C. Adamson, Chairman of the House Committee on Interstate and Foreign Commerce, "Millions of tons of equipment, hundreds of thousands of soldiers and all sorts of supplies have moved on schedule-time during the past seven months and without a hitch. No country, even where they have government-operated railways, ever duplicated this feat. The government got just what it wanted and the railroad chief-men, whose life-work has been railroading, were there to carry out our wishes." [1]

General Conclusions and Recommendations

Full information should be collected in time of peace as to the extent and resources of the railway system of a country. This information should be digested in a form that would be readily accessible for an intelligent comprehension of its availability, in the event of war. It should include sectional maps on a large scale, showing the location of the lines and the extent of second and multiple tracks, with the character, arrangement and capacity of station-facilities; and they should be kept up to date. The equipment on each line should be carefully recorded and checked up occasionally. The valuation-surveys now being made of the railway system of the United States would greatly assist in such a work.

From this information, the make-up of trains for the movement of characteristic military units should be determined, as to the number and kind of cars required, and as to the length and weight of trains that could be dispatched over each probable line of communication, with regard to gradients and the siding and terminal facilities at points of entrainment and detrainment; and the intermediate points should be established at

[1] Railway Review, October 27, 1917.

which transfers would be required. The length of time required for any given train-movement over any given line should be based primarily upon the rated tonnage-capacity of locomotives of different classes at the economic rate of speed of twelve to fifteen miles an hour, with allowance for necessary detentions for rest and refreshment of troops. On this basis, there would be little difficulty in providing for the return movement of the same trains, under efficient train-dispatchers and yardmasters. The preparation in advance of voluminous military time-tables would be unnecessary and, in fact, become impracticable by reason of current changes in details of operation. Any experienced railroad superintendent who is familiar with the local situation can arrange for such train-movements on sufficient notice, as is done with other emergency-movements. These preparations for warfare in time of peace should be assigned to a special commission of military and railway experts, which should hold its sessions at stated intervals.

The construction of strategic railroads in time of peace is influenced by the foreign policy of the nation. If it be one of continental supremacy, like that of the German Empire, it is not to be considered in connection with the railway system of our own peace-loving democracy. Thanks to the existence of a similar democracy on our northern border, we have neither a fortification nor a sentry on the land, nor a vessel of war on the Lakes, along this border for over four thousand miles from ocean to ocean; and therefore no need for strategic railroads in that direction. The border troubles with our Mexican neighbors may be viewed as transitory, and, therefore, our chief concern is the defense of our extensive coast-line on the two oceans and on the Gulf of Mexico.

The policy hitherto pursued, has looked to the protection of important commercial ports and naval bases by heavy fortifications. The experience in Europe with armored trains, and especially in the defense of the Italian coast on the Adriatic Sea, has given rise to arguments in favor of a system of coast-defense based on the use of such trains mounting heavy guns, with railroad access to every strategic point of defense. Whether it be practicable to utilize such a mobile system in connection with immobile fortifications is a matter which pertains to the judgment of military experts.

Consideration should also be given to the social, industrial and commercial needs of the country for efficient transportation. The immense quantities of track-material and train-equipment that have been shipped to France have drawn heavily upon the productive capacity of the industries which provide for the normal replacements on our own railway system. Up to August, 1917, orders from the War Department for shipment abroad included 150,000 tons of 80-pound rails, 680 locomotives of standard gauge and 600 of narrow gauge, 9000 standard freight-cars and a large amount of narrow-gauge equipment. The order for rails was sufficient to lay 1200 miles of track. The order for locomotives nearly equaled the average increase on our entire railway system in the years 1912 to 1914.[1] Much track-material has been absorbed in the construction of branch-lines and sidings for military purposes within the United States. At Fort Riley, Kan., 13½ miles of track were used for sidings, and the Union Pacific Railroad Company laid a track for 20 miles into the camp at a cost of $1,000,000. The success of military operations of the present magnitude depends greatly upon a proper balancing of the normal requirements for railway transportation with those of a directly warlike character. Unless this balance is maintained, the resulting confusion, interruption and delay in railroad operation of all kinds will long continue.[2]

There need be no question as to the ability of our railway officials and employees to get all the results practicable with the facilities at their disposal. They know how to do this far better than any one else possibly can. They have not only the ability but also the intelligence to direct their means and their strength as whole-heartedly to the service of their country as any other class of their fellow-citizens. In criticizing their work, it would be well to consider the distinction between coördination and coöperation. Within the war zone, it is coördination that is required; a coördination of military and railway experience under military control. Outside of that zone, coöperation should be sought; the coöperation of stout arms and of willing hearts in a common cause.

In the annual report of the War Department for 1917, Secretary Baker appreciates the work performed by the railroads in transporting soldiers and supplies, despite the difficulties under which they have labored. He concurs in the statement of the Quartermaster General that "of those who are now serving the nation in this time of stress there are none who are doing so more whole-heartedly, unselfishly and efficiently than the railroad officials who are engaged in this patriotic work."

[1] Canada also contributed the rails from 1100 miles of track on the Transcontinental lines where they were virtually parallel.

[2] The withdrawal of employees for military service diminished the efficiency of the British railways to such an extent that, by the end of 1916, it became necessary to release 150,000 railway employees from military duty; being 25 per cent. of the normal force and 50 per cent. of those of military age. Many of these have assisted in the construction and operation of railways in the military zone in France. — Railway Age Gazette, April 13, 1917.

CHAPTER IX

OPERATION

Qualifications and Needs of Railway Operating Officers

Operative efficiency is the summation of the several factors of Railway Efficiency. For the efficient handling and use of these factors, an executive management is needed — a management that should not only have adequate knowledge of the agencies, means, and methods required for railway operation, but should also possess ability for the correlation and control of the manifold resources at its command. Knowledge is the basis of efficiency. It is acquired by experience and by research. Control is assured through organization, training and natural ability. These are the essential elements of successful management.

He who operates in isolation knows nothing of what others are doing. By research, are gathered together the diversified experiences of those who have personally acquired information in any department of knowledge. It is the merit of work of this character that it renders the experience of each laborer in one of these departments available for all who are similarly employed, thereby preventing the useless expenditure of time and energy in repeatedly seeking solutions of problems which have already been solved.

Exact information as to the behavior of materials and of structures under the conditions prevailing in railway operation is a matter of paramount importance. The failure of either of these elements of engineering-practice to fulfill its expected resistance to the strains to which it is to be subjected, may involve loss of life as well as of property and reputation. The researches of Dr. Charles B. Dudley into the qualities of steel rails, and of P. H. Dudley as to train resistance have been of conspicuous value, as well as the classical experiments of George Westinghouse and Sir Douglas Galton for determining the coefficients of brake-friction. Important experimental tests have been conducted by several railroad companies at great expense in the development of the electrification of steam-railroads, and valuable work of this character has been done in technical schools. The experimental method of investigation is of such unquestionable value as a measure of operative efficiency that it should be placed on a more systematic footing, so that its results may exert a more general influence throughout our railway system. This purpose is facilitated by the organized associations of persons who are interested in the same field of research.

Value of Engineering and Railway Technical Associations

The several engineering societies have contributed largely to the fund of information concerning railway construction and operation. The earliest engineering society in England, the Institution of Civil Engineers, was chartered in 1828, contemporaneously with the advent of railway transportation. The American Society of Civil Engineers, which held its first annual meeting in 1867, has given much attention to the theory and practice of railroad engineering directly, as well as indirectly in its investigations of the properties of building-materials and of the extent and character of structural strains. The American Society of Mechanical Engineers, founded in 1879, has given valuable aid in the development of the mechanical features of railway operation, as has the American Society of Electrical Engineers in the electrification of steam-railroads. The decrease in the loss of life and property due to the investigations made by the Bureau of Explosives is suggestive of the beneficial effect upon the public welfare that might follow upon the foundation of a bureau for such experimental investigations under the supervision of the American Railway Association.

In the details of operation, the associations of railroad officials have been of such substantial benefit that they are deferred to by the American Railway Association in the establishment of operating-standards. Instances may be cited in the experimental tests of power-brakes by the American Railway Master Mechanics Association, and in the investigations by the Master Car-Builders Association of the merits of automatic couplers. The Locomotive Dictionary and the Dictionary of the details of car-construction prepared respectively by these associations are recognized as authorities on these subjects. The recommendations as to rail-specifications of the American Railway Engineering Association have the published approval of the American Railway Association.[1]

The most important of the railroad technical associations is the American Railway Association, which was organized in 1891 as a successor to the General Time Convention. Originating in meetings of transportation officials for the correlation of time-tables, its functions have been extended to cover the entire range of railway operation. Its conclusions on matters pertaining to this field of activity, though nominally of the character of recommendations, have assumed a mandatory character, its membership being composed of the railroad corporations themselves as represented by their executive officials. As these officials are, by natural selection, the ablest and most experienced men in their profession, it follows that no better means could be devised for securing efficient methods for the operation of our railroad system.

This fact has assumed a national importance in connection with the

[1] For list of railroad technical associations, see Appendix IX, Note I.

entrance of our country into the European War. On April 6, 1917, the day of the declaration of war, the Executive Committee, which had already appointed a Special Committee on National Defense, prepared an agreement for the operation of the lines in its membership under the management of this committee. By this action, all the railways in the United States, with over 220,000 miles of line, were merged in one system for the efficient application of their resources to the national welfare, "without special consideration or compensation." This momentous transformation of over six hundred separate corporations into one homogeneous body could not have been so readily accomplished through any other instrumentality.[1]

The association of railway officials for research in the field of operation has transcended national boundaries in the organization of the International Railway Congress, which has held its sessions at intervals of about five years in the European capital cities and, in 1905, in Washington. Its Eighth Session in Berne, in 1910, was attended by over six hundred delegates from every country in the world in which there is a railway in operation. These delegates not only represented railway corporations, but also the governments themselves. The Congress has been recognized officially by the governments of the countries in which its sessions have been held and, since the Session in London, in 1895, the American Railway Association has been specially represented, as also the United States Government through the Interstate Commerce Commission and by specially appointed delegates.

The service rendered by these associations has been undertaken in a field of activity in which almost the entire sum of human knowledge has been made available in the application of railway operation to the requirements of civilized society. All around the ever-extending horizon of this field, practice has furnished a firm foundation for the fulcrum upon which the lever of research may be pushed out into the region of the unknown. So long as the balance is preserved on the side of experience, hypothesis becomes theory and the field of human knowledge is securely enlarged.

Conservatism in Adopting Improvements

Reluctance to adopt novel methods or appliances is not appreciated by enthusiasts for progress. In the performance of a great public service, however, it is advisable not to venture hastily into untried fields, but to temper inventive ingenuity with the discretion born of experience. For experience serves to distinguish in a novelty that which is impracticable, or which is useless for the purpose for which it is proposed. The coördination of the several elements in railroad operation, which is essential to its efficiency, may be seriously disturbed by unwise experimental interference.

[1] See Chapter VIII, pp. 444, 445.

For this reason, the management of a great railway is naturally reluctant to adopt untried appliances or methods, even though they have a promise of merit.

The introduction of a single locomotive with increased axle-loads may affect the factor of safety in many bridges on the line, or of the rail-section in general use. Articulated locomotives must be turned on "Y" tracks and be specially housed, unless new turntables and enlarged roundhouses be provided. A single car of unusual length can not be placed beside a freight-house without interference with the door-spacing, and consequently with the speedy handling of freight.

The introduction of novel methods or appliances, therefore, should be conducted in a conservative manner, with due consideration of its effect upon the financial condition of the railway company and upon the general conduct of operations. Their introduction into the general scheme may seriously disturb the coördination which is essential to efficient operation. Nor should such changes be made general before their usefulness has been fully developed, as was done with the vacuum brake on the New York Elevated Railway. The original "straight" air-brake was likewise superseded by the present system in which the action of the air pressure is reversed. Similar experience followed the introduction of automatic couplers.[1]

The adoption of automatic signaling required an extensive alteration of the appliances and methods of the manual block-system, which had been so long in use that their application to train-movements had become ingrained in the minds of employees, and which represented a very considerable capital investment that thereby became useless. The introduction of steel rolling-stock similarly upset the routine of construction and maintenance in that department by requiring an entire change from wood-working to metal-working machinery and the substitution of machinists for carpenters. In a still greater degree would the general electrification of steam-railroads subvert appliances and methods of operation to which generations of employees have become accustomed, with the abandonment of locomotives and of mechanical plants representing a large part of existing railroad capitalization.

Before adopting any new measure for economy in operation, its effect upon the existing situation should therefore be carefully considered. For increasing the tonnage of trains, there was required an extensive collaboration in the introduction of cars of larger capacity, of more powerful locomotives, of stronger bridges and of longer sidings. To make the improvement effective, there was necessitated a rearrangement of classification-yards, the adoption of new plans for making up trains, as well as other modes of operation, and a general reorganization of the freight-service.

[1] See "American Railway Management," p. 38.

Statistical Methods

The stronghold of criticism of railroad management is Statistics, which, as defined in the Century Dictionary, is "A systematic collection of numbers relating to the enumeration of great classes, or to ratios of quantities connected with such classes, and ascertained by direct enumeration." It may here be more tersely considered as the systematic analysis and classification of facts numerically. To what practical use may statistics be put, as so defined? Primarily, to compare the past with the present situation of affairs in any undertaking or enterprise, or to compare the situation of some one enterprise with that of others of a similar character, the purpose being to draw some conclusion from the comparison that may assist in increasing the efficiency or in detecting the weak spots of any such organization.

With such objects in view, there should be ascertained the character of the statistics which would best serve this purpose. There must be sought some classification of the facts that are relevant to that purpose,—statistics which may assist in a synthesis of the general business environment, or in an analysis of the operations of the respective organizations under consideration. All else is irrelevant and tends to obscure a view of the environment, or to retard an investigation of such operations. We want to know whether we are doing as well as we might, and, if not, in what respects we are deficient. Where is the lost motion of misdirected energy? Where is the leak, the wastage of power or of labor, of time, of materials? For such a purpose, statistical statements are not to be confounded with balance-sheets. It is not a question as to profit and loss, but of the efficiency of the organization or of the administration. We have not only to exclude irrelevant facts, but also to avoid erroneous deductions from relevant facts. Apply these ideas to the available statistical information upon any subject of practical importance and what will be the result? Every business man's office or library is furnished with volumes of such statements, and what use do they make of the most of them? How many of these ponderous volumes rest tranquilly upon the shelves that they encumber, with leaves uncut and with bindings covered with dust? Yet thousands and even millions of dollars have been expended in their compilation, and statistical bureaus go on grinding them out, like the salt-mill in Hans Andersen's story-book.

If this be a fair statement of the innocuous desuetude of such statistics, in what respect are they lacking in practical value? Evidently, in so far as they are unfitted for the uses to which they should be applied; and this because they are largely based upon unpractical methods, upon methods devised by men without experience in the occupation or enterprise from which the facts have been obtained. Furthermore, because their classification has been overburdened by the enumeration of irrelevant details. No busy man has the time to wade through hundreds of pages of columns of figures which can not be directly applied to his own affairs. He wants that information predigested and made available for immediate assimilation. Therefore, let all irrelevant facts be excluded from such publications, as also the innumerable details with which they are frequently overloaded. Then, too, the statistics should not be so delayed in publication as to have become stale and useless under current conditions. To have practical value, they should relate to the immediate past, not to that past which is so remote as to savor of antiquity. We do not want to compare the performance of the steam-turbine with that of Watt's pumping engine, but with that of compound reciprocating engines.

Besides the irrelevancy and voluminousness of much of the information compiled by statisticians, the terms in common use in statistical literature are also open to criticism. Those most frequently to be met with are the Maximum, the Minimum and the Average, as the economic factors deduced from the array of numerical facts. The importance is readily perceived of the Maximum, as being the highest attainable, and of the Minimum, as being the lowest; but the Average is a term of which the importance is often overestimated in considering an actual business-environment or the efficiency of an organization. There are many possible gradations, in either of these cases, between the Maximum and the Minimum; but the Average, as an actual fact, can occur but once. If figures may be made to prove anything, this is true of "the deadly parallel," and of the equally deadly average. The one may be used to compare things essentially dissimilar, and the other is but the arithmetical mean between perhaps widely different conditions, and actually represents but one of them.

Use of Averages

The term Average, as employed in Statistics, is capable of four different meanings, according as it refers to the arithmetical mean, the "weighted" arithmetical mean, the "median" or the "mode"; and statisticians admit that, in the application of the average to any individual case, the result may vary accordingly. An average may therefore be considered as an arithmetical abstraction, of value in the application of a widely extended series of data to some general proposition, but leading to incorrect conclusions when applied to individual cases. The wider the range of observation, the more numerous the number of individual instances observed, the fewer and simpler the characteristic data, the more reliable will be the average thus obtained.

Such averages may be of value in the construction of mortality tables for a life-insurance company, but not in determining the relative efficiency of railroad managements. In applying the principle of the average to such a case, it should include a consideration of all relevant data and exclude all that are irrelevant. In whatever terms it may be expressed, its practical value lies in its illumination or coördination of many individual cases of a similar character. For averages may be based upon data too limited as to number, or in groups affected by dissimilar characteristics.[1]

An average may be based upon too small a number of individual cases to be of value or, as is sometimes done where the number of cases is very great, resort is had to an "estimated" value. It is not possible to deduce, from the bare statement of the figure of an average, the number of individual instances considered in its computation, or whether one may be dealing with a mere estimate. Those who make the estimates, as a rule, know only a small part of the individual cases, and perhaps give a judgment from limited observation. Estimated values occur sometimes without being evident. In such cases there is danger of ascribing to the value in any question greater reliability than it actually possesses. Relative numbers having the character of averages are also often estimated when there are no sufficient data for their computation. Every estimate must be regarded as simply an approximate value. It may be quite accurate in some cases, but there is no certainty. Modern statisticians endeavor therefore to secure data sufficient to enable them to dispense with estimates.[2]

It is further to be noted that averages can only be applied in connection with numerical data. Therefore they are inapplicable to cases in which qualities, as distinguished from quantities, are under consideration.[3] There may have been a disregard of unity as to time and place in selecting the data for an average. The agreement of data obtained from distinct observations is not always easy to establish. In different returns, the same object may have been differently defined, and an average so computed has little scientific value. In different periods of time, essentially different causes may have been operative.[4] Nor have averages any bearing upon the relation of cause and effect. "The statistical investigation of causes therefore gives rise to errors only too frequently, and a perfect theoretical certainty can never be obtained."[5] "The resort to estimated averages may be induced by a desire to hasten their publication or to limit the expenditure necessary for a more thorough investigation and classification of numerous observations." "The more the statistics are simplified, the less the cost

[1] "Not infrequently the incorrect use of averages has led to erroneous conclusions, and to contradictions which have shaken our confidence in statistics. Averages, indeed, are only applicable under strictly defined conditions, and conclusions based on averages are likewise permissible only within well defined limits." "Statistical Averages." Preface. Dr. Franz Zizek, University of Vienna. Translated by Professor W. M. Persons. Henry Holt & Co., 1913.

[2] See "Statistical Averages," pp. 38–41.

[3] "Qualitative individual observations do not permit the computation of an average." *Ibid.*, p. 7.

[4] "Averages for large districts or for whole countries would obliterate all characteristic differences; the larger the territory, the farther removed the average would be from reality, without other compensating advantages aside from securing a formal, unified expression." *Ibid.*, p. 78.

[5] *Ibid.*, p. 120.

of preparation and publication. Thus financial considerations are often of influence, which is especially the case with official statistics."[1] From this statement of the genesis of the statistical average, it may be seen how easily erroneous conclusions may be drawn from statistical comparisons. Even the trained statistician is exposed to errors when he does not realize that the averages which he compares refer to non-homogeneous groups. "This explains also how the same statistical material, when differently handled and grouped, seems frequently to prove exactly opposite assertions."[2]

The value of statistical statements for the comparison of the past with the present situation of any business or enterprise, or between any two of them contemporaneously, is vitiated if the conditions be dissimilar under which such comparison is made. Conclusions profoundly affecting the public welfare, as well as private interests, are to be drawn from such statements; and it is essential to both that the methods employed should correctly represent the conditions to which they are related. The first step in a statistical inquiry is the collection of data. Such data should not only be relevant to the purpose in view, but should also be free from the misleading effect of dissimilar conditions as to time, place or qualities, and especially free from individual bias or lack of knowledge on the part of the persons engaged in the collection of observations and of their aggregation in homogeneous groups.

When this work has been faithfully and intelligently accomplished, the next step in classifying the data numerically for the determination of an average, is to establish a common unit for their measurement. Units of measurement vary in name in different periods of time, in different countries, and even in neighboring communities. This is the case even with units nominally the same. Hence their relative values may likewise vary. There are units of cost in different currencies, and units of efficiency in differing terms as to weight, size or force. It is said that there is but one unit which is recognized as a universal standard of measurement — the motion-picture or cinematographic film-unit. Some basis of uniformity should be sought, and this is especially true as to averages. An average is virtually an unrelated instance, save when the things to be compared are of a similar nature and are presented under similar conditions; as for example, the production of commodities of a uniform character.

Railway Statistics

In the application of statistics to the specific case of railway operation, it should be recognized that statistical statements for purposes of comparison, either of performance on two railroads or on any one railroad at different periods, are not only valueless but misleading, unless based upon uniform data. For this reason, certain statistical methods in vogue are

[1] "Statistical Averages," p. 84. [2] *Ibid.*, p. 105.

unfit for practical purposes, and are misleading when utilized to maintain a political thesis.[1]

The analysis of the cost of operation may be satisfactorily treated with reference to a particular railway system, where there is an approximate uniformity in the conditions which affect the character of the comparison. But the data applied in the analysis of the operations of one system can not be utilized with profit in an analysis of the operations of another, unless it be done under some standard of comparison which is common to both. Locomotive-mileage means one thing on one system and something else on another. Passenger-mileage is an absurdity when applied to the cost of the service rendered. Ton-mileage is merely an expression of the product of weight and distance units, without relation to the characteristic features of freight-rates and classification, of the varying proportion of dead weight to paying loads, of empty car to loaded car and train-mileage, or of other things which affect a comparison of the cost of service under different conditions and circumstances. Then, too, the relation of cost to revenue is not a relation of efficiency, but of profit. A certain basis of percentage is in no sense a standard of efficiency. With decreasing revenues, it signifies the necessity for retrenchment; with increasing revenues, it may savor of extravagance.

The operations of a railroad company being primarily undertaken as the means of carrying persons and things from one place to another, economic efficiency in this respect first attracted the attention of official statisticians. A committee on Statistical Inquiry was at one time appointed by the American Railway Association to take this matter up with the statistician of the Interstate Commerce Commission. With the light that might have been thrown on the subject from information gathered at first hand, and with its intelligent treatment by experts in railway operation, a unit of efficiency might have been established that would have been available as a standard of comparison of the relative economic efficiency on different railway systems. This would have been a valuable aid toward the creation of a science of Railway Economics but, for some unexplained reason, the matter met with disfavor and the work of the committee was ignored in the Proceedings of the Association.

The Ton-mile Average and Passenger-mile Unit

Operations in the Transportation Department proper more directly affect individual interests, and information in connection with such operations is eagerly desired by those who are thus interested, as well as by others who are actuated by a disinterested regard for the public welfare. The obvious distinction between the transportation of persons and of

[1] As to different periods of time, a locomotive which in 1900 cost $12,000, cost $23,000 in 1910, for the same service on the Empire State Express, upon the New York Central & Hudson River Railroad.

things led at once to a separation of the characteristic data of each of these features of railroad operation, and to the establishment of the corresponding units of measurement in the ton-mile and the passenger-mile. The calculation of averages based on this distinction of data and its application to freight and passenger service is so readily grasped from a superficial investigation of the subject that the ton-mile and the passenger-mile averages have become applied to railway operations in general to a far greater extent than can be justified from a careful consideration of all the conditions under which railroad service is conducted. This is an important matter, as it lies at the bottom of most of the differences of opinion, and of the dissensions which have arisen between railroad managements and the communities dependent upon railway transportation.

The data for the ton-mile average are obtained by multiplying the weight of each shipment by the number of miles that it has been transported. This information, obtained from the way-bills, is aggregated in the railroad auditor's office and is then reported to the office of the Interstate Commerce Commission, where it is totalized and is used in establishing the ton-mile average for the railway system of the United States as a whole.

The term "ton-mile" may have one of four meanings. It may include the car and lading, or the lading only, or revenue-freight only, or it may also include company-freight; and the Committee on Statistical Inquiry of the American Railway Association proposed yet another in the "equated ton-mile" defined as "the sum of the weight of the car and lading and an allowance for the resistance offered by friction, grades and curves, multiplied by the mileage of the car." The ton-mile average is the official basis for comparisons of operative efficiency, and the unit of the long-haul and short-haul yardstick for the measurement of rates, yet it recognizes no distinction as to the relative weight, bulk, value or other qualities of the respective commodities transported, whether they be perishables, silk or coal.

The ton-mile basis, as originally applied by the Interstate Commerce Commission was inapplicable to the distinctive conditions prevailing in different sections of the United States. The railroads were afterward divided for this purpose into ten groups, following in general the political division into states. The information corresponding to this division was used to obtain a ton-mile average for each group. This grouping divided the operation of important railroad systems so arbitrarily as to render the conclusions thus obtained inapplicable to their operations, and the grouping was simplified by a division of the whole area into three territorial districts. Consequently, group-averages for the period prior to the year ending June 30, 1911, are not applicable for comparison with subsequent periods.

The passenger-mile unit is based upon the product of numbers by distance. Weight is not a factor in the computation of the passenger-mile average. Its value is not affected by the qualities of the person transported, as the ton-mile average is affected in its application to freight traffic by the qualities of the commodities transported. The passenger-mile basis is, however, open to the objection that it does not recognize the different classes of equipment provided for different classes of traffic and does not cover the transportation of baggage, mail and express matter by passenger-trains.

After separating from the mass of data derived from railway operation, those items which may fairly be assigned respectively to freight or to passenger traffic, the remainder by far exceeds the relative proportion of either. Yet no statistician has so far devised a formula for consolidating ton-miles and passenger-miles in a common transportation unit, for the comparison of efficiency, or of the cost of service. There is no common basis of comparison. The character of the service performed in the transportation of passengers is so radically different from that in the transportation of freight that it would be an absurdity to measure it by a weight-unit.

Yet a common unit of transportation is all the more to be desired, since the relation of ton-mileage to passenger-mileage is not uniform in different sections of the United States, nor on different railroads in the same territorial district.[1]

As applied to different railroads in the same territorial district in 1914, the ratio in the Eastern District varied from 75 to 1 on the Bessemer & Lake Erie Railroad to 0.15 to 1 on the Long Island Railroad; in the Southern District it varied from 113 to 1 on the Virginian Railway to 2.1 to 1 on the Florida East Coast Railway; and in the Western District from 56 to 1 on the Duluth & Iron Range Railroad to 0.3 to 1 on the Northwestern Pacific Railroad.[2]

Ton-miles and passenger-miles are not recognized as transportation units elsewhere than in the United States; therefore they are not available for any comparison of operative efficiency between this country and foreign countries. This matter was discussed at length at Berne, in the International Railway Congress of 1910. The conclusions then reached are given in Appendix IX, Note II. The substance of these conclusions, which

[1] RATIO OF TON-MILES TO PASSENGER-MILES

Year	Eastern District	Southern District	Western District	United States
1911	8.5 to 1	10.0 to 1	6.0 to 1	7.68 to 1
1912	8.7 to 1	10.2 to 1	6.4 to 1	8.00 to 1
1913	9.4 to 1	10.8 to 1	7.2 to 1	8.73 to 1
1914	9.0 to 1	10.7 to 1	6.8 to 1	8.20 to 1

[2] See "Special Statistics," Appendix VII, Table XIX.

represent the views of the most eminent railway experts throughout the world, may be summarily stated to this effect: that it is practically impossible to establish any uniform system of transportation units and averages which would be generally applicable to comparisons of the cost of service, but that such statistical standards, as measures of operative efficiency, are not unattainable and are greatly to be desired. For the determination of the operative efficiency of the railway system of the United States as compared with that of the railway systems of other countries, this is not a matter of material importance, as the average cost and rate per ton-mile in freight-service in this country is generally assumed to be lower than on any other national railway system. This statement does not, however, apply to the passenger-service.

There are other standards of measurement which are regarded as transportation-units, besides ton-miles and passenger-miles. Freight is moved in car-loads, and the cubic-content capacity of a car, as well as its weight-capacity, causes the car-mile unit to correspond more closely to the qualities of commodities in general than is the case with the ton-mile unit. Freight in car-loads constitutes a train-load, and freight-trains are rated as to the number of cars and their gross weight, and not as to the net weight of their contents. The ever-present problem for solution by transportation officials is the concentration of the most ton-miles in the fewest car-miles, and of the most car-miles in the fewest train-miles. The car-mile unit is of more value in passenger-train service, for it is only under special conditions that the number of passengers in a train affects the number of cars in a train. The car-mile unit also covers the mail, baggage and express cars and other equipment in a passenger-train, which the passenger-mile does not.

Transportation Units of Practical Value

Transportation units should cover all the important elements of train-service. Freight-trains may consist of coal-cars loaded to ten per cent. above their normal capacity and to the full rating of the locomotive at an economic rate of speed, or they may be made up of both empty and loaded cars, or of cars lightly loaded in proportion to their empty weight, as with perishables in refrigerator-cars, and moving at a speed of perhaps thirty miles an hour. Such transportation-units are of even less value in their application to passenger-trains, as that character of traffic is controlled far more by considerations of social efficiency. Passenger-train service may be conducted at medium speed in crowded local trains with ordinary equipment, or in high-speed trains equipped with sleepers, parlor-cars, observation-cars, dining-cars and café-cars, occupied by but few passengers in proportion to the weight of the train, and cared for by porters, cooks, waiters, barbers and stenographers.

An important feature of train-service that is not recognized in any of these transportation-units is the relative tractive power expended in surmounting ascents differing in length and degree of gradients and at differing rates of speed. The basis of transportation is traction, and the fundamental test of operative efficiency is the economic production of tractive power and its use in transportation. In railway transportation, tractive power is exerted at the tender draw-bar, and the expenditure of power is determined by the dynamometer at that point. The quantity of power thus exerted is in proportion to the resistance offered by the train, which varies with its weight and speed and with the effect of gravity on ascending and descending grades. The only unit of tractive power for the practical comparison of train-service in general is, therefore, the dynamometer-pound of draw-bar pull, varying as it does in quantity with these changing conditions.

The unit of draw-bar pull represents the work done in overcoming the resistance offered by gravity and friction, but not the important factor of the time in which any certain quantity of tractive power has been expended; whether in one hour or in two. This factor is included in the indicated horse-power unit of one pound raised one foot in one minute. The horse-power unit therefore measures the efficiency of the locomotive as a mechanism for the application of power in traction, but a step farther must be taken, to reach the ultimate basis of traction. This basis is to be sought in the production of energy from the evaporation of water into steam, through the agency of heat. Therefore, in its last analysis, the basis of efficiency in railway transportation is economic fuel-consumption, and the basic unit of fuel-consumption, and therefore of railway transportation, is the heat-unit, whether applied to the development of tractive power directly by steam or indirectly by electricity.

The practical application of the heat-unit may be exemplified on any division of a railroad by making up a train of coal-cars, for instance, loaded to their normal capacity and attached to a dynamometer-car. If such a train were to run over a certain division in each direction at the most economical rate of speed, and the draw-bar pull were graphically recorded, the total quantity of horse-power thereby expended in overcoming the resistance offered by friction and gravity would have been experimentally ascertained, and consequently the horse-power per ton required for moving a train over that division under ordinary conditions. By comparing the weight of coal, of the same quality, consumed under these conditions, with that consumed by other locomotives similarly rated and under similar operating conditions, the relative consumption of fuel in firing could be determined. Furthermore, by ascertaining the combustion-value of the coal, there could be stated in heat-units the relative efficiency of different locomotives as tractors, in performing the same service. Ultimately, a standard might be determined in heat-units per ton of train at different rates of speed, for that division.

By such means, there might also be ascertained the percentage of tractive power which had been utilized in any given period, and the relation of the locomotive-plant to the train-requirements. Such an investigation might be extended into the draft of power in different classes of train-service, or in dead loads and paying loads. The total train-resistance would represent, in foot-pounds, the combined weight of trains and the distances and differences in elevation overcome in actual service. Allowance should be made for the expenditure of power for incidental purposes other than traction; for brakes, blowers, injectors, electric light, steam-heating and other accessories. From all these data, a unit of service might be obtained which would assist in obtaining correct comparisons of efficiency and cost, in detecting weak spots in operation, and in stimulating the activity of the organization. It is to be noted that methods available for comparisons of economic efficiency in the application of tractive power to train-service bear no relation to the relative cost of performing that service in currency-units.

Operative and Economical Efficiency

There are, in reality, three aspects of railway efficiency; operative efficiency which represents production value, commercial efficiency which represents cost value, and social efficiency which represents service value.

The "cost of service" is an expression so frequently used in criticisms of railway management as to warrant a consideration of its actual significance. The cost of service varies with the physical and social environment in which it is performed, and also in different periods of time. It is, therefore, manifestly impracticable to compare the cost of train-service in different countries as a measure of efficiency, or in different regions, or in the same region at different periods of time, except with respect to certain matters in which uniform conditions prevail.

Operative efficiency is displayed in the economical use of materials as to quantities and qualities, and in the manner in which labor is applied, also in the ingenious disposition of these instrumentalities for the purpose in view. A comparison of costs can only be logically applied when seeking to ascertain the relative margin of profit in the charge for rendering a service, either in production, maintenance or distribution. The fuel-bill is about twelve per cent. of the total cost of operation of our railway system. The variation in the cost of fuel does not directly affect operative efficiency, but variation in its quality does.

After operative efficiency has reached a certain stage, the cost of the service increases proportionately in a greater ratio. The process may be likened to the increasing ratio of energy required to approach a vacuum. Each successive stage of reduction in the pressure of the inclosed gas is procured at an increasing ratio of exertion. So the successive stages in the approach of operative efficiency toward an ideal standard are only attained at an increasing ratio of cost.

Economic efficiency is displayed in the ratio of the work performed to the energy so exerted. The efficiency of the locomotive is determined by its output of tractive power in proportion to the accompanying expenditure of heat-units. But in all comparisons of railway operation it should be recognized that the ratio of actual to theoretical performance, as a matter of economic efficiency, is more or less dominated by varying standards of social efficiency. Yet social efficiency, regardless of cost, is not to be commended in railway transportation. Traffic-efficiency lies in a judicious balancing between economic and social efficiency, so that the cost of the performance may not exceed the value of the service rendered. Speed and convenience are regarded as variable factors in the service rendered to travelers, but the fixed factor in passenger-train service is safety. The acme of safety is entire freedom from abnormal conditions that might result in injury to the persons transported.

In an adequate comparison of railway operations, apart from the cost of the service, the data must be measured in terms of efficiency, and the units of efficiency in the several operating departments must conform to the data respectively characteristic of each of them. For this reason, transportation-units are not applicable as a measure of efficiency in other departments. Yet any considerable alteration in the character of train-service may affect every department of railway operation; as for instance, increasing the length of freight-trains to save train-mileage affects the weight of locomotives, the strength of rails and bridges and the length of sidings. Increased density and frequency of train-service leads to the construction of second track, to the introduction of expensive signaling apparatus and to increased cost of maintenance in the roadway department. But there would be no evidence of increased operative efficiency in the ton-mile average. Switching-mileage finds no place in transportation-units, though fifteen per cent. of the number of locomotives upon our railroad system are engaged in that service, and the estimated switching-mileage equals twenty-five per cent. of the locomotive road-mileage. It also represents a considerable quantity of unrecorded car-mileage; and further, the cost of car-repairs due to this mileage is far greater proportionately than is caused by an equal quantity of recorded mileage. Neither does the ton-mile average recognize the service performed by work-trains, nor take into account the empty-locomotive mileage. The trackage equipment, employees and station-maintenance included in terminal operations incur expenditure that is not represented in transportation-units. The mechanical departments, except as to running-repairs, are not essential factors in railway transportation, and their efficiency as to output should be compared with that of other shops in the same line of production.

The correlation of these auxiliary operations of a railway company with its primary service of transportation upon a statistical basis of uniformity is impracticable. Nor is it an easy matter to arrive at a basic unit which would be readily acceptable for comparisons of efficiency and cost in these several departments. The basis of all phenomena is the reaction of energy and matter, and until some unit has been devised which will serve as a measure of that reaction under all conditions, it will be impracticable to measure all the reactions of energy and matter that are essential to railway operation by any single unit, or to establish any single statistical average as a basis of comparison of operative efficiency.

Railway Organization

The service in railway transportation is a complexity of mental and physical activities, exerted through the intervention of appliances and devices which are controlled by agencies in separate places and at different times. This complexity of activities must be so coördinated as to work harmoniously for a special purpose — the transmission of persons and things. Upon first thought, it seems impracticable to condense within reasonable limits an adequate description of that which may be termed the art of railway operation. For it should comprise a reference to every fact essential to a comprehension of the present state of that art, if it is to be of value to those who are associated in its practice or who desire to obtain a theoretical acquaintance with it. It is given to but few men to acquire an adequate conception of efficient railway operation entirely from personal experience, and such opportunities are confined to those only who have attained the higher offices in railway service.

The art of railway operation is like a maze of many-colored threads, from which each independent operator is disentangling here and there a strand for a web of his own weaving; but for the entire mass to be utilized in a fabric of orderly design, some clew must be found to the unraveling of the tangled skeins. Organization is the clew to the labyrinthine web. "Order is Heaven's first law," and organization is the prime essential in efficient service of a multifarious nature.

The aim and intent of the organization of industrial activities is their coördination to a common purpose. Any combination of individuals may be readily coördinated under a single executive official, so long as their field of action is under his personal observation; but when that field extends beyond his personal purview, it becomes necessary to depute some part of his authority to subordinates. Here is the parting of the ways between two methods of organization, the departmental method, or the delegation of power in specific lines of authority to deputies who remain under the direct supervision of the central executive, and the divisional method, or the delegation of full authority over these several lines of activity to separate deputies in specific fields of action. Contention as to the relative advantages of these methods has existed since warfare became a recognized profession. The officer on the staff favors the departmental method, while the line-officer prefers the divisional method; and this contention has accompanied the development of isolated railways into connected systems covering thousands of miles of line.

Railroad operation proper — that is, the service of transportation by rail and steam — should include all of the instrumentalities and functions essential to that service, and should be divested, as far as may be possible, of all extraneous relations. Administration should be separated from operation. A consideration of this problem may be simplified by viewing the railway company itself as a corporate body, apart from its functions as an instrumentality of transportation. The corporate authority is lodged in the board of directors. There, responsibility must ultimately rest as to matters affecting corporate powers and obligations, and thence supervision should directly proceed over matters of policy and finance. The business of the treasury and of the auditing offices and the legal relations of the corporation, should remain within the direct personal observation of the board of directors, however extended may be the field of corporate action.

All questions of policy should be determined by the corporate authority — the board of directors, and should include the establishment of charges for the services rendered in transportation; also the terms and conditions of employment and the rates of pay of those by whom that service is performed. By relieving the operating officials of attention to these matters, their time and thought will become more available for the efficient discharge of the important duties for which they are directly responsible, and their personal relations with employees will be placed upon a more satisfactory basis. Operating officials would not then be looked upon with distrust, as being the head and front of opposition to efforts to improve the conditions of employment of those with whom many officials had previously served on terms of equality, and would gladly preserve their friendly relations.

The experience of ages has led to the adoption of this course in military organizations. Commanding generals do not regulate such matters. They merely conform to the regulations established by the corporate authority of the State. This statement also includes the purchase of materials and supplies. Operating officials have had no experience as traders. Their experience has been in doing things, and they are not conversant with commercial usages and the course of trade. In fact, neither they nor their subordinates should have any business-relations with salesmen. Specifications for supplies should be framed in language sufficiently exact to prevent misunderstanding as to quality. Storekeepers should make requisitions long enough in advance of the time that supplies will be required for the purchasing department to place its orders advantageously. They should also be careful that the supplies, as purchased, conform strictly to the specifications.

As the corporate powers and obligations of a railway company are not organically connected with the service of transportation, so the same may be said in a lesser degree of that field of activity which is covered by what is known in our railway parlance as the Traffic Department, a term applied in other countries to our transportation department. The assertion that this department is not necessarily a component of transportation-service may not be obvious, yet it could be entirely severed from that service without affecting the efficient transmission of persons and things. The traffic department is essentially an organization for affixing the charges and for collecting and accounting for the revenues, in connection with the rendering of that service. The exigencies of competition gave it a factitious prominence in popular opinion because to it had been assigned the fixing of rates and, incidentally, the power to adjust them to the relative advantage or disadvantage of individuals and of communities.

Since this method of competition for business has ceased with the stabilization of rates by legislation, the duties of the traffic department, in this connection, have been restricted to the coördination of the enormous volume of classified and specific rates into orderly tariffs for submission to the government bureaus and in appearing before them in support of their approval. It has also to supervise the application of these tariffs in the offices in which way-bills are made out and where passenger-tickets are sold.

The principal value of the traffic department in actual railroad operation is in its capacity as an organ of publicity. It is really the only medium through which the transportation officials are kept in touch with the requirements of the public under the conditions varying with the seasons and with the occasional demand for extra train-service. It is also the medium for extending information as to train-schedules and the facilities afforded to travelers for their comfort and convenience, and as to points of interest to tourists. Through its offices in the principal trade-centers and by its traveling-agents, it is kept informed as to the wants and complaints of those whose interests are affected by the manner in which the transportation service is conducted. For these reasons, the traffic manager should be in a position to advise with the general manager and, if necessary, to bring to his attention any shortcomings in the operating departments that may affect the interests of travelers or of shippers, or the revenues of the company.

For the separation of administration from operation to be successful, the board of directors must direct, in fact. They must place the welfare of the corporation foremost in mind and in acts. Committees should be given supervision of the departments reporting to the board; not to interfere with their management, but to become so familiar with their details as to be capable of discussing them intelligently at board-meetings. All matters relating to operation which were of an administrative character and had received the approval of the board should be promulgated in the form of by-laws that would be beyond the authority of operating officials to modify.

The administrative organization would then consist, primarily, of the President and Board of Directors. The Secretary would have charge of the archives, and also of the publication of resolutions of a public character and of by-laws which affected the operating departments. The Treasurer would head the financial and pay departments. The Auditor would have charge of the accounting departments. The Purchasing Agent would fill the requisitions for supplies which had been approved by the Board, in conformity with the specifications provided by the operating departments. Through the Traffic Manager, the traffic department would report directly to the Board.

The operating organization would then be upon a solid foundation. Freed from responsibility for rates of freight and passage, for trading for supplies, for discussing wages, hours and other conditions of employment, operating officials could direct their experience and energy to securing efficiency and economy in operation; not economy in driving sharp bargains, but in the judicious application of means to ends; getting full value for every pound of material and for every hour of labor applied in railroad service.

Divisional Organization and Authority

Efficiency in the exercise of the functions involved in railroad operation may be defined as the coördination of the resources of static and dynamic engineering for the transmission of persons and things with safety, convenience and dispatch; and this definition may be considered as the summation of the art of railroad operation. This art has been developed by practical experience in the combination of the functions once separately performed by carriers, by coach-drivers and by persons engaged in the design, construction and maintenance of the vehicles and the roads upon which they operated.

In the early stages of this development, the coördination of these several functions under a single official was practicable. With the extension of service over longer lines, and with increasing traffic, there came a delegation of power along specific lines of action which resulted in the establishment of the roadway, the mechanical and the transportation departments. In the further stages of railway expansion, these lines of action extended into regions beyond efficient supervision from a single center. To overcome this difficulty, it became necessary to divide these regions into separate fields of action, and to delegate in each division some of the powers before exercised directly from the central source of authority.

The problems here presented are these: At what stage in the expansion of a railway system should the divisional method of organization be introduced, and to what extent should the central authority be delegated to the deputies in charge of the divisions? As a general proposition, there are two elements involved in any complex activity, — improvement in methods and coördination in their application to a specific purpose; or briefly, progress and uniformity. These elements are by nature in opposition, and the character of any organization is affected by their relative activity. The most efficient organization is that in which their reaction has been resolved into a diagonal of forces on the line of least resistance. Here a distinction is to be drawn between the establishment of methods and their application to concrete cases. It is the distinction between theory and practice that suggests a standard of delimitation between the authority reserved to the department chiefs and that transferred to the division superintendents.

This line of demarcation may be more readily drawn in matters of a physical or technical nature than in those which pertain to the transportation-service proper; that is, to the transmission of persons and things. For here an additional factor becomes active in the transition of control over the service, as its performance passes from one division to another. It is not an isolated service, but a successive service, which must be coordinated as to time and place for it to be efficient. It is a continuous campaign, conducted incessantly, in which many agencies, widely dispersed, must each of them perform a certain act at a certain time in a certain place, in order that a multiplicity of interdependent movements may continue without interruption. Here, the art of railway operation is put to the test, and successful results must depend upon the coöperation of those who establish methods with those who apply them. The safety and comfort of passengers must be provided from the time that they enter a station at the beginning of their journey, and in carrying them promptly to their destination. Commodities must be properly loaded and dispatched and their delivery in good order insured. To fulfill these requirements efficiently, the art of railway operation includes the preparation of time-tables, of train-rules and station-rules, of regulations for the loading and unloading of freight-cars, for collecting them into trains and for their subsequent distribution, for tracing their movements and for inspecting their condition, as well as for other operations incidental to the main service of transportation.

The division of the field of operation should depend upon its extent. Close supervision and thorough knowledge of current conditions are essential to the successful conduct of train-service. These qualifications, so necessary in a superintendent of transportation, can not be efficiently applied in a field too extensive for frequent personal observation. The limits of a division should be determined by the density and character of the traffic, by the number and location of branch lines and by the magnitude of division and junction terminals, for a division superintendent should be able to reach any point on his division within his working day.

On American railroads, the divisions are generally from 200 to 500 miles in length, with a tendency to long divisions. On many of the principal systems there are two general superintendents and, on a few of the longer systems, two general managers also, with a vice-president in control of all the operating departments.[1]

The authority of the division superintendent over his division should be undivided; no man employed upon it should be able to say him nay. This assertion brings into question the relation of the other operating departments to the transportation department. As the roadway is the basis of transportation by rail, the maintenance of the track is indissolubly associated with train-service. The division roadmaster must conform to the requirements of the transportation department in all matters affecting the passage of trains. The division superintendent should be quick to detect deterioration in the surface of the track and promptly call the section foreman's attention to it, as well as notifying the roadmaster. The roadmaster should have direct control of the section and work-train forces and should appoint their foremen, preferably from the better class of employees.

The chief of maintenance-of-way should see to providing materials, supplies and work-train appliances, and should appoint the division-roadmasters. Their authority, however, should extend only to the maintenance of the superstructure. All work on the substructure, save in emergencies, should be directly under the chief of maintenance-of-way, including bridges, buildings and signal apparatus, with the employees and appliances engaged in such work.

The relations of the motive power and of the rolling-stock departments to the transportation department are less direct than are those of the roadway department. Indeed, the designing and construction of locomotives and cars might be entirely dissociated from railroad operation without affecting its efficiency and, under some conditions, perhaps advantageously. It is only in the current maintenance of train-equipment that either of these departments has any direct connection with train-service. Enginemen and firemen have not, necessarily, any more to do with locomotive-repairs than conductors and brakemen have to do with car-repairs. The whole train-crew should be directly responsible to the division superintendent; and also the operations of the motive power and rolling-stock departments, so far as running-repairs are concerned, including roundhouses and workshops. A division master-mechanic, with a roundhouse foreman, a shop-foreman and a yard-repair foreman, would bear the same relation to the division superintendent that the division roadmaster would. The superintendents of the motive power and of the rolling-stock departments should furnish equipment in good order to meet the requirements of the transportation department, and should supervise the tech-

[1] See Appendix IX, Table III.

nical work of repairs on the division. The locomotive-inspector or traveling-engineer on each division should report directly to the division superintendent as to the handling of the locomotives, and to the superintendent of motive power as to their condition. All repair-work, except running-repairs, should be concentrated in shops under the control of the chiefs of the mechanical departments, as well as the designing and construction of equipment.[1]

The traffic department has but little direct connection with the transportation service, save through the accounting offices of the freight and passenger agencies. At important stations these agents, who collect freight-charges and sell tickets, should be appointed by the traffic manager, in order to relieve the station-agent of an unnecessary responsibility. All way-bill forms and blanks and passage-tickets should be supplied by the traffic department. It should also have the adjustment of loss and damage claims for freight and baggage, but the investigation of such claims should be made a duty of the transportation officials, who have hitherto not felt their responsibility in such matters. The total loss of an article intrusted to a railroad company for transportation must have occurred in a train-accident or by thievery. Partial loss or damage is either the result of careless handling, or recklessness in making up trains. In any of these cases, the prevention and remedy are in the hands of the transportation officials and rest largely with the division superintendent.

The main object to be kept in view in railroad operation is transportation service and, for this service to be efficiently performed, the division should be the unit in the operating organization. Therefore, every instrumentality affecting that service within the division should be under the control of the division superintendent. The transportation service proper is composed of three elements: the station-work, or the receipt and delivery of the persons and things transported, which is under the station-agents; the yard-work, or the assembling and distribution of the vehicles in which the transportation is performed, which is under the yard-masters; and the road-work, or the movement of these vehicles in trains to their respective destinations, which is under the train-dispatchers. The yard and station work is supervised by the trainmaster and the road-work by the chief dispatcher.

These men are the active agents through whom the superintendent exercises authority over the service and, within their respective fields of action and under the rules of the company, they should have a free hand for its successful accomplishment. They are called on to do desk-work as well as field-work, and, since the latter is far more necessary for efficient operation, it should be given the preference. As far as practicable, they should be relieved of correspondence, reports and statistics by the assistance of a clerk, a stenographer and a telephone. One hour more a day thus saved

[1] See Chapter III, pp. 62, 63.

from desk-work and given to the conduct of the field-work will be fully worth the additional expense. This suggestion is applicable to the division master-mechanic and the division roadmaster. All of these men have been fitted for their positions by practical experience in their respective departments. They are better qualified for that work than for desk-work, and they prefer it.

Although the divisions are the basic units of railway operation, they are but links in a continuous chain of service, and they must be closely connected for the current of traffic to pass freely through their junctions. At these points, the terminal service should be altogether within the jurisdiction of one of the adjacent divisions, unless the terminal is so extensive as to form a separate division.

The operation of a union-station is usually supervised by a committee of representatives from each of the lines in interest. If this committee be composed of the higher operating officials only, that supervision is likely to be superficial. Better results may be expected if the committee be composed of the superintendents of the adjacent divisions, who are more familiar with the local situation.

Purchasing and Distribution of Supplies

Materials and supplies should be under the charge of a general storekeeper, responsible to the practical operating management. All requisitions from division storekeepers should be collated in his office for approval by the chief operating official, and for reference to the purchasing agent in ample time for obtaining bids and placing contracts in due season for delivery. Such supplies as fuel and track-material should be directly under the supervision of the general storekeeper and concentrated at convenient points for distribution. Minor supplies, especially those of intrinsic value, should be issued under his direct supervision. With these exceptions, supplies may be more conveniently delivered in periodical installments directly to the division storekeepers. Their monthly statements of receipts, issues and stock on hand will enable the general storekeeper to determine the manner in which supplies shall be distributed with regard to the requirements in the operating departments and to the prevention of unnecessary accumulations of stock. This matter, as well as insuring that the delivery is up to specifications, will be materially benefited by systematic inspection from the general storekeeper's office.

Materials and supplies for the division, should be distributed by the division storekeeper. The only exception should be the stationery and tickets used in the freight and passenger offices, which should come from the traffic department. The storekeeper should be responsible to the division superintendent for keeping supplies of every character on hand in quantities sufficient to meet the anticipated requirements of the operating departments.

Evidences of Inefficiency

Satisfactory train-service can not be expected without reliable motive power. Train-delays due to locomotive-failures are indications of relaxed inspection or of shop-mismanagement which reflect upon the vigilance or the ability of the superintendent of motive power. In like manner, delays or accidents due to such defects in rolling-stock as flat wheels, defective draw-gear or inefficient brake-rigging, or to hot boxes, are evidences of mismanagement in the rolling-stock department, as are also cases of damage from leaky car-roofs. The general condition of the freight-equipment may be inferred from such inspection reports as the annual inspection-reports of the Division of Safety of the Interstate Commerce Commission, which give the comparative percentage of defects in safety-appliances on roads with equipment of 10,000 cars or more. When such reports show that in five years not more than 1.5 per cent. to 2 per cent. of the total number of cars inspected, belonging to a certain company, were found defective in this respect, it may be inferred that the shop-efficiency on that road was of a higher character than on another road which, during the same period, showed a percentage of defects varying between 7 per cent. and 14.6 per cent.[1]

The appearance of its passenger-train equipment affects a railroad's reputation almost as much as does the character of its train-service. Coaches requiring revarnishing, shabby interiors, insufficient lighting or heating apparatus or appliances, poor ventilation, window-sashes that rattle or that are raised with difficulty, neglected toilet-fixtures, all tell a tale of mismanagement, just as inattention to cleanliness does. Train-conductors' reports of such matters are not sufficient for their correction. The train-equipment on a road with considerable passenger-traffic requires the attention of a traveling-inspector as much as such attention is required for its motive power. The failure to maintain equipment in good condition is not always attributable to incapable master-mechanics. It may be due to insufficient shop-room or appliances or labor; to whatever cause it may be due, it is a reflection upon the operating-management and the poorest kind of economy.

Low joints in a railroad track likewise proclaim to every passenger that fastenings are loose and that the track is out of line, that rails are badly worn and the timber decayed, that frogs and switches are defective or that the drainage is neglected. These faults are so obvious as to require but a superficial observation to make them known to the officials directly in charge of the maintenance of way, who should deal with them either by furnishing the requisite track-material or by changing the roadmaster on the division. The condition of the substructure is not so readily apparent. Deterioration in bridges or the gradual failure of foundations can only be

[1] See Chapter IV, p. 131.

discovered by experienced engineers. For this reason, the Engineer of Bridges should be in responsible charge of all matters connected with roadway substructure. The maintenance of buildings on railway property is usually intrusted to him, as requiring knowledge and experience of a technical character.

General Management

Within the limits prescribed by the by-laws of the company, all the instrumentalities connected with operation, as distinguished from administration, should be controlled by a chief executive or general manager, in order that responsibility for results may be clearly determined. This official should have authority adequate for the efficient discharge of the duties of this important office, through which continuity between the operating-divisions is maintained.

Here, the functions necessary to this end are directly exercised, including the preparation of time-tables and the arrangement of sleeping-car, parlor-car and dining-car service, also the supervision of ferriage, lighterage and other marine service, as well as the relations with similar officials on other lines. Supervision of the train and station service is exercised by a general superintendent and his assistants, one of them being specially charged with the distribution of freight-equipment. The superintendence of mechanical operations in the motive-power and rolling-stock departments and of the maintenance of way should also be concentrated in officials connected with this office. The general manager and these assistants should not only be experienced railroad men, they should also have become so familiar with the local situation as to be able to decide matters, in an emergency, from their personal knowledge of the surroundings, rather than from more or less inadequate or biased reports from their subordinates.

In the management of the operating departments, the transportation department should have the primary consideration. On its efficiency depends that success in operation which adds to the reputation as well as to the revenues of the company. Prompt movement of the traffic is the key-note to success; for this means also safety, convenience and dispatch in the transportation of persons and of commodities. From the daily statements of train delays and accidents, of the tonnage moved, of cars handled, of train-loads and of the freight-situation at stations, the general management is informed as to the manner in which the transportation service is being performed, and of irregularities which should be speedily investigated and the proper remedies promptly applied.

The relation of the general management to the several departments in the field of operation may be likened to that of the brain to the other members of the human organism. Here, the reaction takes place between the sensations received from the outer physical and social environment and the intellectual processes by which the organization responds to the conditions and circumstances prevailing in that environment. For this response to be effectual, the information received from the environment must be ample and timely, and the action thereon must be prompt and appropriate.

The information required by the general management is voluminous and multifarious. It includes reports as to the extent, character and conduct of the current traffic, as to the condition and disposition of equipment, and as to the progress of work connected with the maintenance of way. Requisitions for labor, materials and supplies are to be examined and also recommendations as to additions and betterments for the improvement of the service. These documents are to be analyzed with the aid of statements from the auditor's office covering ton-mileage, passenger-mileage, car-mileage, locomotive-mileage and train-mileage, and with reference to the monthly reports of revenue and expenditure. Investigations of accidents and irregularities are to be dealt with, and the office must keep in touch with changes in commercial, industrial and social requirements, with the doings of legislatures and railroad commissions, and with current events affecting the interests of the company or of the public welfare.

Many of these matters are to be abstracted in proper form for speedy consideration or to be conveniently filed for ready reference, as may be required for conferences with officials or with the president of the company, with officials of other companies, or in interviews with other persons or representative bodies. This work, as well as the routine correspondence, requires supervision by a capable office assistant who should, as far as possible, relieve the chief executive from intrusion by casual visitors. The right man in this position is of inestimable value to the chief executive officer.

Inspection Department

Much importance is attached, in a military organization, to inspection as an assurance of efficiency. It is a duty intrusted only to officers of special experience, who strictly observe the manner in which the service is conducted and the evolutions are performed, with careful attention to the condition of arms, accoutrements, materials and supplies. It would be well if the same importance were attached to such inspection in railway operation, where it is usually done in a desultory way and is not recognized as a special feature of the organization. If a systematic, continuous and thorough inspection of methods and appliances be of value in the destruction of lives and property, it is surely of value in their preservation during their transportation by rail. Inspection of this character should extend to the condition and conduct of every operating department. It should be intrusted to experienced men, reporting directly to the chief operating official. Inspection should not be confounded with detection. The inspector is not to search for hidden faults in individuals, but to act as the eyes of his chief in matters open to personal observation. He should neither criticize nor commend, but should simply report what he has seen. His reports should be brought to the attention of the officials concerned in them, with a view to remedy or improvement where necessary.

Railway Engineering. Construction Department. Improvements and Standards

In contradistinction to the department of operation, the department of construction is under the engineering staff. The extent and character of its organization should depend upon the magnitude of the system and its environment, upon the policy pursued in the provision of equipment and as to the extension of the system by the construction of additional line. The work of betterment never ceases on a prosperous railroad. It goes on continually in every operating department. It is directed to the improvement, enlargement or re-construction of freight and passenger station buildings and terminals, to the introduction of heavier locomotives, cars of greater capacity, rails of heavier section and bridges of greater strength, and to corresponding improvements in design and construction.

On such a scale, the engineering staff is necessarily divided into mechanical engineers and civil engineers, the one dealing with dynamic problems and the other with static problems. In each of these subdivisions careful attention must be given both to the practical and the theoretical aspects of each problem. All these matters are to be worked out in theory and materialized in plans, specifications and estimates by specialized experts, and then considered and approved by the chiefs of the respective departments of civil or mechanical engineering, before they are submitted to the chief operating official by whom they are to be presented to the board of directors.

Standards can not be preserved unless they are rigidly respected. For this reason, they should neither be prematurely established nor enforced over a widely extended system, without reference to the varied requirements under different conditions as to the character of the traffic, or as to the physical and social environment. Yet standards can not be immovable, for uniformity bars the way to progress. They must respond to advances in the arts to which they refer. A style of locomotive with a certain wheel-arrangement became so identified with railroad operation in this country as to be generally known as the "American type." Its principal parts were standardized in design, and to some extent in dimensions, which facilitated construction and kept down the cost of production. The desire to utilize the steam-pressure to better advantage led to the introduction of compound engines, which affected the design of the cylinders and of the steam-distribution. The demand for greater power caused a change in boiler-design, which required a different wheel-arrangement. The use of superheated steam also affected the boiler-design, as the mechanical stoker is now affecting the fire-box design, which will be more materially changed if the use of pulverized fuel should become general. Now, nearly all of the standardized features of the American type of locomotive have disappeared from the articulated locomotive, which is itself being superseded, to some extent, where conditions are favorable by the electric tractor.

Theory, Practice and Experience

The antinomy between Theory and Practice is active in the application of nearly every measure intended to increase operative efficiency. The theorist is optimistic; the practical man is conservative. He is antipathetic to any innovation in the ways to which he has become accustomed. From familiarity with conditions in his department, he perceives consequences that are not apparent to the advocates of the proposed changes in appliances and methods. Yet improvement can only come through changes; and a satisfactory conclusion to these encounters of Theory with Practice is only to be reached by bringing their respective advocates together in council, in order to reconcile their differences and to establish a common basis on which they will stand. If this course be pursued, the theorist, the staff-official, will recognize the practical objections to the method or the appliance that he advocates; and the practical man, the line-official, will comprehend the advantages which are claimed for the proposed change. This is an important matter, for the success of measures for improvement may depend largely upon a favorable reception by those who are to apply them in practice.[1]

Experience comes from having done a thing so often that one has learned the correct way to do it through profiting by mistakes. Thereafter, the mind reverts to the correct way without especial effort of the reasoning faculties. Men availed themselves of the properties of matter for ages without a knowledge of the laws of gravitation and of motion. So it is that the experienced railway official arrives at a practical solution of the problems pressing upon him, without being able to satisfy inquisitors as to the process of reasoning by which he arrived at conclusions. It is one thing to evolve methods for increased efficiency from scientific reasoning; it is another to apply them successfully, particularly in dealing with human beings and not with automatic machines.

Advisory Boards

Changes in methods or appliances must ultimately be authorized by the chief operating official. Whether this be done directly or by delegation, the responsibility is his. When one thinks of the field in which this responsibility is exercised upon a great railway system, it is plain that he can not determine such matters solely from personal acquaintance with

[1] "The practical spirit is the art of solving present difficulties by the quickest and simplest devices, with only an immediate realizable benefit in view." Ferrero, "Ancient Rome — Modern America," p. 144.

them. He must give attention and direction to current affairs; through him the relation of the corporate authority is maintained with the property under his charge, and upon his attitude toward its social environment, the welfare of the company largely depends. His decision in most matters relating to operative details must be guided by second-hand information, from statistics or from reports, rather than from personal observation. Therefore he should fully avail himself of the knowledge and experience of his assistants, whether of the line or staff. How can such information be more satisfactorily obtained than by taking counsel with them personally? By bringing the staff and line officials together to discuss their differences of opinion in his presence, he will have light thrown upon the subject of debate that he can obtain in no other way, and will be able to arrive at a more correct conclusion concerning it than from written reports or by separate interviews.

The assembly of department officials for such purposes should be something more than an occasional conference. It should be made a feature of the operating organization formally constituted as an advisory board and its conclusions formulated in reports; for its value will depend in a great measure upon the character of its organization. It should have the privilege of initiating a discussion of any matter of operating interest, and should be furnished with any information pertinent to such a discussion.

An advisory board also provides the opportunity for controlling future expenditures instead of directing criticism to those already made. For the control of future expenditures with assurance of obtaining the anticipated results, there is no plan so effective as the establishment of an annual budget in detail, and in monthly allotments to the several departments. The preparation of such a budget requires a minute analysis of operating expenditures and an intimate acquaintance with operating details. It should therefore be based upon an estimate from the chief of each department, and these estimates should be freely discussed in the advisory board, with the view of keeping the total estimated annual expense as low as may be considered practicable to secure efficient service. Expenditures occasioned by emergencies should be provided for by separate appropriations, as also the cost of betterments. Under a budget established in this manner, each department official who has had a share in its preparation will recognize his personal responsibility for keeping within his allotment, and will feel assured, if he has done so, that he will not subsequently be subjected to unpleasant criticisms.[1]

Distribution of Railway Personnel

A discussion of the principles governing the formation of an operating organization is necessarily confined to general terms, for operating condi-

[1] For a detailed account of the organization and proceedings of such an advisory board, see "American Railway Management," p. 153.

tions vary so widely with the magnitude of a system and with its environment that, in the application of these principles, there is occasion for a corresponding variation in details.[1] An idea may be formed of the relation of the several departments of a railway organization to the system as a whole, from the statement of the distribution of the persons employed on railroads in the United States, given in Appendix IX, Tables IV and V. The persons so employed in 1914 numbered 1,710,000, being at the rate of 667 employees per 100 miles of line.[2]

Employees on the French railways may be divided into four classes:

1. The Central Administration, consisting of directors, managers, general secretaries and office-staff, of about 3000 persons;
2. The Traffic Administration, including station-masters and their assistants, clerks, train-conductors, ticket-examiners, guards and gangers, all together about 150,000 persons;
3. The Rolling-stock and Locomotive Departments, of engineers, heads of sheds, drivers, firemen and workmen, numbering about 100,000 persons;
4. The Way and Works Department, of about 90,000 engineers, architects, heads of sections, foremen and workmen.[3]

This total number of about 343,000 persons is employed on about 30,000 miles of line, or at the rate of about 1143 per 100 miles of line, which is somewhat less than double the rate on our railway system.[4]

[1] For detailed plans of organization, see "Economics of Railway Operation," M. L. Byers, 1908, pp. 1–67, and also "Freight Terminals and Trains," J. A. Droege, 1912, p. 167.

[2] OCCUPATION OF RAILROAD EMPLOYEES IN THE UNITED STATES IN 1914, PER 100 MILES OF LINE

General offices		40
Transportation		
Trainmen	121	
Stationmen	79	
Train-dispatchers	16	
Switchmen	15	231
Shopmen		150
Roadway		150
Miscellaneous laborers		91
Floating equipment		5
Total		667

[3] "Professional Education," G. Allix, Journal des Transports. Translated in Bulletin of the International Railway Congress, July, 1914, p. 676.

[4] EMPLOYEES ON FRENCH RAILWAYS. 1913. (31,400 MILES)

DEPARTMENT	NUMBER	PER 100 MILES	PER CENT.
General offices	3,000	10	1
Traffic	150,000	500	44
Mechanical	100,000	333	29
Roadway	90,000	300	26
Total	343,000	1,143	

In 1910, the employees on the railways in the United Kingdom of Great Britain and Ireland, less heads of departments, numbered 608,750 on a line-mileage of 23,389 miles. The nomenclature of the different classes of employees differs so materially, as given in the Board of Trade Report, from that in use in this country that it is impracticable to make a comparison in detail. In making a comparison of the total number of employees, those employed in Great Britain in team-delivery to and from the stations should be deducted, numbering 24,986, which would make the average 2505 per 100 miles of line. It may be noted that about seven per cent. of these employees were under eighteen years of age.[1]

On the Italian State Railways, in 1910–1911, with a line-mileage of 8903 miles, there were 148,727 employees, being an average of 1671 persons per 100 miles of line.

These several averages per 100 miles of line compare as follows:

United Kingdom	2505 employees
Italian State Railways	1671 employees
French Railways	1143 employees
United States	667 employees

In the Eastern Traffic District, where the density of traffic is much the same as in Great Britain, the average is 1143 persons, or just the same as in France; in the Southern District, the average is 601 persons; and in the Western District, 472 persons, per 100 miles of line.

Training for Railway Employment

With the increasing complexity of railway operation, and of the relations of railway managements with the political and social environment in which they operate, there is a growing necessity for a higher standard of educational qualifications, both of a general and of a technical character, in those who aspire to the higher positions in railroad service. For this reason, the haphazard way of employment that has long prevailed must be replaced by more systematic methods of appointment and promotion. Attention has been given to this matter in Continental Europe, and it has been the subject of deliberation in the meetings of the International Railway Congress.

In Germany, advancement to lower-grade positions is facilitated by the attention paid to primary education, and the higher grades are as readily filled by graduates from the technical schools. With these advantages, and as a result of the discipline derived from a general military training, the suitability of the average railway employee in Germany for promotion is probably superior to that which prevails in other countries.

In Austria and Switzerland, and to a limited extent in Russia, applicants are required to furnish certificates from a technical school for appointment in certain departments, in others from a professional school, and from

[1] See Appendix IX, Note VI.

a university for the higher positions. But appointments made on educational certificates have not proved satisfactory, and a railway training school in Austria, founded in 1899, was discontinued in 1913, owing to the disappointing results in practice.

In other countries of Continental Europe, appointments to original positions seem usually to be made by lower-grade officials without any special educational requirements, dependence being placed upon subsequent practical experience for advancement. Pupils from technical schools are, in some instances, taken on probation, those who show sufficient capacity being selected for promotion.

The English railway companies have encouraged an intellectual training for men already in the service, by the establishment of libraries and of courses of lectures on technical subjects. Since 1846, the London & North-Western Railway Company has maintained a "Mechanics' Institute" at Crewe on this plan. Recently, there has been organized in this institute a four-year course of lectures in mechanical and electrical engineering and in building-construction, with diplomas for graduates. A number of apprentices attend the electrical laboratory one afternoon in each week.

In connection with a Mechanics' Institute, founded in 1851, for the education, recreation and social life of its employees resident in the Metropolis, the Great Eastern Railway Company has established evening classes in subjects related to mechanical and office work in railway operation. There were 958 students in these classes in 1910–1911. Institutes of this character are maintained by the Midland Railway Company, the Lancashire & Yorkshire Railway Company, the Great Western Railway Co., the London & South-Western Railway Company, and the North-Eastern Railway Company.[1]

It would not be practicable to require a previous educational qualification for the 1,700,000 employees of our national railroad system, beyond that provided in the public schools. The principal railroad systems have taken some steps toward preparing their employees for advancement, following the policy pursued by the British railway companies. It is also possible on any railroad to give the young employees the opportunity for an insight into the more theoretical features of railway operation in the departments in which they are employed. An apprentice who has had two years of shop-experience will be much benefited by six months spent in the engineering drafting-room, and will be better fitted for subsequent usefulness as a shop-foreman. It would be of advantage to a bright young brakeman to have a similar opportunity in a yardmaster's office. So it would be with station-employees as to desk-work, to telegraph-wiremen in an electric plant and to messengers in the telegraph-offices. It is a more

[1] For further information, see "History of Inland Transport," E. A. Pratt, pp. 417–427.

difficult matter to present such opportunities to laborers in the roadway department. Yet it is from this body of employees that section-foremen are obtained, many of whom are worthy of an opportunity for better positions. This opportunity is afforded on some roads to section-apprentices selected for advancement.

On the other hand, young men who enter railroad service with a technical education should have their theoretical acquirements tempered by some practical experience alongside of their less-favored compeers. It is good for them to rub up against the mechanics in the shops, or with the foreman on the track, on bridge-repairs or on a work-train. Six months of such experience may serve to increase their respect for practical knowledge and for the men who possess it, as well as to moderate their estimate of the comparative value of theoretical information. The maintenance of a rational balance between the two methods of training is such an important matter that it should have careful consideration by a special committee of the American Railway Association.

The empirical method has been found deficient also in France for furnishing men from the lower grades suitable for the medium-grade posts, or for higher positions intrusted with managing-authority. Moral worth, a spirit of initiative, good conduct and zeal are taken into consideration, but it is still found necessary to gauge preferment by progressional acquirements, and then help to develop proficiency by experience. Attempts have been made to base appointments and promotion solely upon examinations, but this method was found to favor unduly those who had been fortunate in opportunity for preparation for the examinations. The relative markings depended too much upon chance in establishing a right to promotion by which the railway management was bound. It was also a severe strain upon experienced men to submit to such an examination. "Instruction is good at all times of life but not 'schooling,'" as Montaigne remarked.

About 1913, the Orleans Railway Management organized a preparatory course for examinations for promotion, with a series of sixteen lectures on train-service, technical service, commercial service and accounting-service. These lectures were distributed in printed form among the employees. The applicants for promotion were afforded opportunities for personal observation at signal-stations, freight-houses and similar places of interest in railway operation. While still in the experimental stage, this method is regarded as promising good results; yet the head of the transportation department, by whom it was organized, remarked that "such a system is not indispensable for obtaining higher-grade employees; and experience has shown that the desired qualifications can be acquired by practical work with the advice and example of their chiefs. But the operation of railways has become so complex, the questions involved are so numerous and sometimes so delicate, that no means should be neglected for preparing and enlightening those who are to become managing-officials.[1]

Methods of Employment in the United States

The empiric method still prevails in the United States. Certain benefits are derived from the deliberations of the societies of railway officials, and still more would follow upon the establishment of the advisory boards, as hereinbefore described. In 1905, the American Railway Association recommended a set of rules to determine the "Physical and Educational Qualifications of Employees" for adoption by its members. Applications for original employment and for subsequent promotion were to be made on a prescribed form, on which were noted the age and race or nationality of the applicant, with statements as to his personal habits, family relations, previous educational opportunities and occupation. He was then to submit to a rigid physical examination and, for employees in train-service, to a further examination as to acuteness of hearing and correctness of vision, with color-tests. The educational examination was to determine the applicant's ability to read, write and speak the English language, and his acquaintance with the primary rules of arithmetic, with some notations of his apparent mental characteristics. The physical examination was to be conducted by the company's surgeon, but no mention is made of the person who should make the other inquiries. No further discussion of the subject appears in the subsequent proceedings of the Association, except a casual reference to color-tests, nor are there any means of ascertaining the extent to which these rules have been applied by its members.

There would seem to be no doubt that any applicant for railroad employment that comes within the purview of workmen's compensation laws, or of the administration of a pension-fund, should make a formal application covering the information pertinent to these matters, and that this application should be recorded for ready reference. The applicant should also furnish such information as to educational opportunities and previous occupation as would serve to indicate his possible qualifications for subsequent advancement. These statements should be tested by a cursory examination, but the physical examination should carefully determine all the points included in the rules recommended by the American Railway Association.

It is sufficient for original employment in manual labor that the applicant should be morally and physically sound, of decent personal habits and able to understand oral or written orders in the English language. The position of foreman should be open to any such employee who had a knowledge of the primary rules of arithmetic. Thus equipped, there is no reason why any man of fair intelligence should not be able to fit himself

[1] See Bulletin, International Railway Congress, July, 1914, p. 676. "Professional Education," G. Allix.

for further advancement. From such men, there should be selected for promotion those who were favorably indorsed by their immediate superiors. As they advanced, step by step, those who had been improperly favored would be gradually eliminated. By this process of "the survival of the fittest," many of the men have made their way who now fill the highest positions on our railway system.

This empiric mode of training for promotion has been justified by its results, in so far as it affects out-door work. For office-work, at the desk or at the telegraph-instrument, there are further required neat and orderly business-habits, quick perception and a facile and legible style of penmanship. To this class of employees, as well as to those in the out-door service, promotion is always open. For what may be called the staff-appointments, educational qualifications of a higher order are indispensable; for certain positions, a special technical training also. Much might be said in favor of the methods followed on the Pennsylvania Railroad system, where professional attainments are prerequisites for appointments in the line of promotion to managing-positions. Certainly that system has gained a world-wide reputation for operative efficiency.

Requirements for Successful Railway Management

The important matter in an operative organization is to get efficient service from it. Excessive concentration of initiative at its central point tends to congestion there, with a resulting lack of vigorous action at its periphery. Instead of one man trying to do the thinking for all in matters of detail, he may be assisted by the mental efforts of all in everything save that in which he alone should do the thinking. The principal part which the head of a great system should retain for himself is not the originating of ideas or the institution of reforms so much as the coördination of the efforts of others in such matters. Here it is that good judgment comes into play, in the exercise of the reasoning faculties, developed by education and by experience; that is, by having learned through an extended series of trials and errors to distinguish that which is practicable or advisable from that which is impracticable or inadvisable.

It makes but little difference in which department of operation the general manager may have received his early training, any more than whether the commanding general may have been promoted from the infantry, cavalry, artillery or engineers. What he needs is a familiarity with the conditions under which railway operations are conducted and with the methods and appliances by which they are performed. Such experience, combined with that mental aptitude for surmounting difficulties, for meeting emergencies and for securing efficiency, which some call good judgment and others common sense, make the successful railroad manager.

The exercise of executive control of a high order requires a combination of knowledge and experience with natural ability, a sense of justice and honesty of purpose. These qualifications have been eminently conspicuous in the men who have brought our railroad system into the state of efficiency by which our national resources have been marvelously developed and our prosperity augmented; and furthermore, by which railway operation elsewhere has largely profited. It is not to be expected of our railroad managements that they have attained the highest possible stage of efficiency, nor is this claimed for them, for the field for investigation in railway operation is continually broadening, as in other fields for research. General practice will always lag behind the pioneers in every art. In this respect, it will be difficult to prove that our railway managements compare unfavorably with those in other countries or with the directors in other fields of production or distribution at home or abroad.

Railway Improvements Originating in the United States. Recognition by the International Railway Congress

In bringing this chapter to a conclusion, it may not be amiss to recount the features of railroad operation which have been benefited by improvements originating in the United States. In the early period of development, the T-rail pattern was introduced into Continental Europe, although Vignolles failed to have its prototype, the "pear-head" rail, substituted in Great Britain for the "bull-head" pattern. The fish-plate, as an accessory fastening to the T-rail, is of American origin, as also the spring-rail frog, and the chilled cast-iron car-wheel. Up to the time of the financial crisis of 1873, improvement in railway operation in the United States, as elsewhere, had not advanced materially beyond the state of the art at the beginning of our Civil War. A new era was inaugurated with Bessemer's invention of converted steel, in its application to countless appliances and processes connected with railway service. The use of compressed air in foundation work, which originated in England, was further developed here with much improved appliances. This may also be said of the use of reinforced concrete, of the art of wood preservation, and of the substitution of the solid-steel wheel for the steel-tired wheel.

Perhaps the most important influence exerted upon railway transportation, however, has been due to the American invention of the swiveling-truck, which has profoundly affected the methods of both construction and operation. Great saving in roadway-construction was made possible by the use of curves of shorter radii than was feasible for vehicles mounted on fixed axles. The swiveling-truck permitted increased loading by the division of weight on a greater number of axles, with consequently increased capacity in proportion to dead weight.[1]

[1] At the meeting of the International Railway Congress at Paris in 1889, commendation was given to the management of the Pennsylvania Railroad for the construction of coal-cars, in which the proportion of dead weight per ton of load had been reduced 31.8 per cent., with a corresponding reduction in cost of construction of 33.8 per cent. and in length of train of 45.6 per cent. At the meeting

In passenger-car construction, the use of the swiveling-truck has been an important gain in the cost of maintenance. By concentrating the spring-action in the trucks, the effect of shocks and oscillations of the wheels on the track is subdivided and diminished in its transmission through the center-pin, with accompanying relief to the body of the car and to its occupants. It also permitted an increase in the length of the carriages, with economy in operation; and the platforms with end-entrances afforded the means for communication through the train otherwise than by the perilous outside running-board.

The radical changes in passenger-car construction which have originated in the United States were availed of for the introduction of toilet-appliances and other conveniences for travelers not provided elsewhere; and, subsequently, to the luxurious equipment of sleeping-cars, dining-cars, parlor-cars and observation-cars, with accessory steam-heating and electric lighting. The isolated-compartment carriages on fixed axles which long characterized European railway operation have yielded to the manifest advantages of the American thoroughfare passenger-cars on swiveling-trucks, and this change has been accompanied by the gradual disappearance of the class-distinctions in travelers to which this isolation was originally due. The efficiency of the quick-action Westinghouse air-brake was not available in Europe until this change was made, but the American automatic close-coupler has not been so generally favored abroad. Conservatism still preserves the link-and-hook system with separate buffers; but the change must come.

The locomotive with outside-connected engines, mounted on two driving-axles and a swiveling-truck, is so well suited to cheap railway construction that it is favorably known as the "American type." The subsequent changes in wheel-arrangement to meet the requirements for greater speed, more powerful traction and economical fuel-consumption have, for the most part, originated in the United States, as is shown by the names popularly attached to these several types. In return, American locomotive construction and operation have been indebted to European practice for the injector, compound engines, outside valve-motion and superheaters, and especially for the articulated locomotive, which has, however, been substantially developed beyond the design and dimensions of the original Mallet type. Incidentally, it may be mentioned that the maximum gradient for traction by adhesion, as established in Europe, was so greatly exceeded in early locomotive-operation in this country as to excite incredulity among European engineers.[1]

The control of train-movements by signaling-apparatus operated manually from isolated stations, which is of English origin, was virtually super-

in 1900, this improvement was referred to as marking an epoch in operative efficiency.

[1] See Chapter V, Part I, p. 145.

seded there by bringing these stations into electric communication; but this system has been revolutionized by bringing the trains also into connection with these stations by the electric track-circuit, and still further by the automatic action of the trains themselves. Both of these improvements are American inventions. The telephone as the means of direct communication between the train-dispatcher and the train-crew, which is rapidly superseding the intervention of the telegraph-operator, is of similar origin, and an American railroad management is now experimenting with wireless train-control.

This account of the indebtedness of other countries to American ingenuity and experience in railway operation might be indefinitely extended by reference to minor improvements in methods and appliances which have gained recognition abroad; such, for instance, as the checking or registration of baggage, the use of electric-motor trucks for handling baggage and freight, train-indicators and other station-appliances; even so simple a matter as the bell-cord and the air-pipe communication between the train-conductor and the locomotive-engineer.

But a more emphatic indication of this fact may be obtained from the Proceedings of the successive meetings of the International Railway Congress, which held its first session at Brussels in 1885. Neither at this session nor at the next two meetings, at Milan in 1887 and at Paris in 1889, had American practice made any considerable impression upon the minds of the European officials who took part in their proceedings. At the St. Petersburg meeting in 1892, a reference was made to "Mr. C. B. Dudley, the learned chemist of the Pennsylvania Railroad," and to his investigations into the physical and chemical qualities of rails; but real appreciation of the merits of American practice by European railway officials dates from the representation of the American Railway Association at the London meeting of the Congress in 1895. The impression then made by the American railway officials, and at the meeting in Paris, in 1900, led to the next meeting being held in Washington, in 1905, and to the publication in English of a separate edition of the Proceedings, as well as of the monthly bulletin issued at Brussels by the Permanent Commission of the Congress.

These improvements in railway operation, which have so profoundly impressed railway managers abroad, and which have so greatly added to the comfort and safety of railway travel throughout the world, have also given to the United States cheaper freight-rates per ton-mile than exist elsewhere.

On this brief statement rests the claim of our railway managements for recognition among their own people and in every land in which railway transportation has been or may hereafter be introduced. But, as a Committee of National Defense, they have a broader and a higher claim upon the gratitude of their fellow-citizens, and upon the friends of liberty everywhere, for the service which they have rendered to the cause of democracy by Efficient Railway Operation.

APPENDIX I

Mileage Statistics

Table I. Railway Mileage of the World

Compiled from the Statesman's Year Book for 1914, and from more recent sources.

	Miles	Miles Total	State-owned	Gauge Other Than 4′ 8½″
North America				
British Possessions				
Canada	29,304		1,772	
Newfoundland	812			3′ 6″
Jamaica	195			
Lesser Antilles	109			
British Honduras	25	30,445		
United States				
United States, proper	261,554			
Alaska	374			
Hawaii	256			
Porto Rico	38			
Panama	47	262,269	47	
Mexico		15,804	8,030	Narrow gauge 9,304 miles
Central America				
Guatemala	594			
Costa Rica	546			
San Salvador	198			
Nicaragua	171			
Honduras	150			
Panama	140	1,799	359	
Cuba		2,331		
Santo Domingo		175		
Haiti		50	50	Light railway
Martinique		139		
Total for North America		313,012	10,258	
South America				
Argentina	20,639		3,338	
Brazil	15,491		6,403	
Chili	6,738		1,982	Meter through Andes
Peru	1,665		1,053	
Uruguay	1 639			
Bolivia	798			
Ecuador	652			
Venezuela	634		68	
Forward	48,256		12,844	

TABLE I. RAILWAY MILEAGE OF THE WORLD — *Continued*

	Miles	Miles Total	State-owned	Gauge, Other Than 4′ 8½″
SOUTH AMERICA — *Continued*				
Forward	48,256		12,844	
Colombia	621			{ 155 miles Meter
Paraguay	232			{ 466 miles 3. ft.
British Guiana	104			
Trinidad	95			{ 4′ 8½″ and 3′ 6″
Dutch Guiana	37			{ 3′ 0″ and 3′ 4″
Total for South America		49,345	12,844	
EUROPE				
Austria	34,918			
Hungary	13,333	48,251	13,114	See notes
Germany				
Prussia and Hesse	24,197			
Bavaria	5,052			
Saxony	2,058			
Württemberg	1,301			
Alsace-Lorraine	1,301			
Baden	1,104			
Mecklenburg	678			
Oldenburg	404			
Royal Military	44			
Private	2,926	39,065	36.139	Narrow gauge 1,369 miles
Russia	36,304			Principally 5 ft.
Finland	2,344	38,648	24,480	
France		31,391	5,556	See notes
United Kingdom				
England	16,233			
Scotland	3,815			
Ireland	3,403	23,441		See notes
Italy	11,015		8,928	
Spain	9,538			See notes
Sweden	8,984		2,908	
Belgium	5,401		2,708	See notes
Switzerland	3,392		1,701	
Roumania	2,333		2,169	
Denmark	2,343		1,217	
Netherlands	2,295		1,102	
Norway	1,946		1,664	See notes
Portugal	1,854		711	See notes
Bulgaria	1,384		987	
Turkey	1,046			See notes
Greece	990			
Servia	974		357	
Luxemburg	326		122	
Malta	8	53,829		
Total for Europe		234,625	103,863	

Table I. Railway Mileage of the World — *Continued*

	Miles	Miles Total	State-owned	Gauge, Other Than 4′ 8½″
Asia				
Turkey		2,836	912	See notes
Cyprus (*British*)		61		
Persia		34		
British India	33,484			
Ceylon	604	34,088	29,317	See notes
Goa (*Portugese*)		51		
French India		59		
Malayan States		857		Meter
Siam	•	877	598	Meter
Indo-China (*French*) . . .		1,264		
China (*proper*)	4,160			
Manchuria	1,800			
Kiau-Chau	272	6,232		
Japan	7,067			
Korea	914			
Formosa	421	8,402	4,870	
Russian Asia		10,586	6,791	
Borneo (*Portuguese*) . . .		130	·	Meter
Java (*Dutch*)	1,393			
Sumatra	219	1,612	1,376	
Philippines				
Luzon	473			
Panay	72			
Cebu	59	604		
Total for Asia		67,693	43,864	
Africa				
British Possessions . . .				
Egypt		3,872	3,109	See notes
Union of South Africa .	8,393		7,848	See notes
Rhodesia	2,406	10,799	2,191	
Nigeria	912		912	
Sierra Leone	271		271	
Gold Coast	222	1,405		
East African Protectorate	586		586	
Nyassaland	113			
Uganda	62			
Zanzibar	7	768		
Mauritius		130	130	
Total		16,974		
French Possessions . . .				
Algeria	2,071			
Tunisia	1,428		1,803	
West Africa	1,522			
Somali Coast	262			
Madagascar	229			
Réunion	78	5,590		
Forward		22,564	16,850	

TABLE I. RAILWAY MILEAGE OF THE WORLD — *Continued*

	Miles	Miles Total	State-owned	Gauge, Other Than 4′ 8½″
AFRICA — *Continued*				
Forward		22,564	16,850	
German Possessions				
S. W. Africa	1,307			
East Africa	745			
Togo	201			
Kamerun	159	2,412	2,381	
Portuguese Possessions				
Angola	642			
Mozambique	360			
San Thomé	9	1,011		
Belgian Congo		862		
Italian Possessions				
Eritrea	74			
Libia	62	136		
Total for Africa		26,985	19,231	
AUSTRALASIA				
British Possessions				
Queensland	4,524			
New South Wales	4,097			
Victoria	3,672			
Western Australia	3,429			
South Australia	2,168			
Northern Territory	145			
Private Lines	944	18,979	18,035	
New Zealand				
South Island	1,682			
North Island	1,207	2,889	2,860	
Tasmania		701	701	
Total		22,569		
New Caledonia (French)		10		
Total for Australasia		22,579	21,596	

Recapitulation		Miles	State-owned	
North America		313,012	10,258	3.3 per cent.
South America		49,345	12,844	26.0 per cent.
Europe		234,625	103,863	44.2 per cent.
Asia		67,693	43,864	64.8 per cent.
Africa		26,985	19,231	71.3 per cent.
Australasia		22,579	21,596	90.5 per cent.
Total		714,239	211,656	29.6 per cent.

NOTES TO TABLE I. STATE-OWNERSHIP, ETC.

	MILES	MILES	MILES
AUSTRIAN EMPIRE			
Austria			
State Railways		8,053	
Private Railways			
Operated by Company	5,637		
Operated by State	430	6,067	
Foreign Companies in Austrian Territory		20,798	34,918
Hungary			
State Railways		5,061	
Private Railways			
Operated by Company	2,102		
Operated by State	6,170	8,272	13,333
			48,251
BELGIUM			
State Railways	2,708		
Private Railways	190		
Light Railways	2,503	5,401	
EGYPT			
State Railways	1,487		
Light Railways	763	2,250	
Upper Egypt—State Railways 2′ 5½″ gauge		122	
Sudan — State Railways		1,500	3,872
RUSSIAN EMPIRE			
Europe		38,648	
Asia		10,586	49,234
TURKEY			
Europe		1,046	
Asia		2,836	3,882

NOTES TO TABLE I. GAUGE, ETC.

	MILES	MILES	MILES
GERMANY			
Standard gauge	37,696		
Narrow gauge	1,369	39,065	
INDIA — *British*			
5′ 6″ gauge	17,189		
3′ 3⅜″ gauge	14,165		
2′ 6″ and 2′0″ gauge	2,130	33,484	
Ceylon			
5′ 6″ gauge	537		
2′ 6″ gauge	67	604	34,088

NOTES TO TABLE I. GAUGE, ETC. — *Continued*

	MILES	MILES	MILES
NORWAY			
4′ 8½″ gauge	1,206		
3′ 6″ gauge	664		
3′ 3⅜″ gauge	16		
2′ 5½″ gauge	60	1,946	
PORTUGAL			
Principal lines, 5′ 5⅝″ gauge			
SPAIN			
6′ 0″ gauge	7,036		
Meter gauge	2,231		
Gauge not known	271	9,538	
UNION OF SOUTH AFRICA			
State Railways			
3′ 6″ gauge	7,383		
2′ 0″ gauge	465	7,848	
UNITED KINGDOM			
Single track	10,302		
Double track	11,650		
Triple track	304		
Quadruple track	1,185	23,441	
5′ 3″ gauge (Ireland)	2,869		
4′ 8½″ gauge	19,873		
4′ 6″ etc. to 1′ 11½″ gauge	499	23,241	

TABLE II. GROWTH OF RAILWAY MILEAGE IN THE UNITED STATES AND THE WORLD

Year	United States			World		
	Miles	Increase	Increase per Annum	Miles	Increase	Increase per Annum
1835	948			1,600		
1840	2,818	1,870	374	4,730	3,130	626
1845				10,000	5,270	1,054
1850	19,021	16,203	1,620	24,491	14,491	1,449
1855				41,000	16,509	3,302
1860	30,914	11,893	1,189	67,111	26,111	5,222
1865				90,000	22,889	4,578
1870	52,914	22,000	2,200	139,110	49,110	9,820
1875				185,000	45,890	9,178
1880	93,296	40,382	4,038	229,916	44,916	8,983
1885	128,000	34,704	6,940	300,000	70,084	16,017
1888	136,883	8,883	2,961			
1890	163,597	26,714	13,357	390,000	90,000	18,000
1893						
1894	168,023	4,426	1,106			
1895	177,746		9,723	500,000	110,000	22,000
1896	181,982		4,236			
1897	183,284		1,302			
1898	184,648		1,364			
1899	187,534		2,886			
1900	192,556		5,022			
1901	195,561		3,005			
1902	200,154		4,593			
1903	205,313		5,159			
1904	212,243		6,930			
1905	216,973		4,730			
1906	222,340		5,367			
1907	227,454		5,114			
1908	233,467		6,013	594,867	94,867	7,297
1909	236,834		3,367			
1910	240,293		3,459	637,000	32,133	16,067
1911	243,979		3,686			
1912	246,776		2,797			
1913	249,776		3,000			
1914	252,230		2,454	714,239	77,239	19,310
	Decennial Periods from 1850			Decennial Periods from 1850		
1860			1,189			4,262
1870			2,200			7,199
1880			4,038			9,080
1890			7,030			16,008
1900			2,895			
1910			4,773	From 1890		12,350
1914			2,984			19,310

Mileage from 1894 according to reports of Interstate Commerce Commission

TABLE III. RAILWAY MILEAGE — UNITED STATES. TERRITORIALLY DIVIDED

Group	Mileage			Increase			
	1890	1900	1910	1900	Per Annum	1910	Per Annum
I–III . . .	63,802	71,336	77,237	7,534	753	5,901	590
V–VII . . .	29,588	37,774	50,626	8,186	818	12,852	1,285
IV, VIII–XII	70,207	84,236	112,694	14,029	1,403	28,458	2,845
Total . .	163,597	193,346	240,557	29,749	2,974	47,211	4,721

Group I to III . . .	North of Potomac and Ohio rivers and East of the Mississippi, exclusive of Wisconsin and including Missouri.
Group V to VII. . .	South of Potomac and Ohio rivers and East of the Mississippi, including Louisiana.
Group IV & VIII to XII	West of the Mississippi river, including Wisconsin and excluding Louisiana.

District	1911	1912	1913	1914	Inc. 1911 to 1914
Eastern	60,881	60,765	60,951	61,184	303
Southern . . .	48,719	49,768	50,460	51,098	2,379
Western . . .	134,579	136,283	138,391	139,948	5,369
Total . . .	244,179	246,816	249,802	252,230	8,051

ANNUAL INCREASE

Eastern	Decrease 116		
Southern	Increase 1,049		
Western	" 1,704		
Total	2,637	2,960	2,454

The Territorial Traffic Districts in I. C. C. report in 1911 conform closely to the Groups in previous reports, except the inclusion in the former of Missouri and lines in Illinois west of Chicago and Peoria to St. Louis, which are now included in the Western District.

The Southern District includes Groups V–VII, except Louisiana.

The Western District includes all lines west of the Mississippi River, including Missouri and the lines in Illinois as above described.

There are minor discrepancies in the total mileage in some of the tables, due to the use of different bases of calculation in successive reports of the Interstate Commerce Commission.

Table IV. Increase in Railway Mileage — 1908 to 1914

Year	Miles	Miles per 100 Sq. Miles	Increase over Previous Years	Miles per 10,000 Population	Decrease from Previous Years
1909	3,367	7.97	0.11	26.20	0.10
1910	3,459	8.08	0.11	26.14	0.06
1911	3,686	8.21	0.13	26.10	0.04
1912	2,797	8.30	0.09	25.93	0.17
1913	2,986	8.40	0.10	25.81	0.12
1914	2,428	8.48	0.08	25.64	0.17
Total	18,723	Inc. 0.50	Av. 0.10	Dec. 0.56	Av. 0.11

Table V. Steam Railroad Electrification

From Scientific American, June 5, 1915

Railroad	Miles of Line	Miles of Track	No. of Locomotives
PRINCIPAL MAIN LINE ELECTRIFICATION IN SERVICE			
New York, New Haven & Hartford	88	500	100
Spokane & Inland Empire	168	187	12
Butte, Anaconda & Pacific	27	90	17
Southern Railway of France	165	205	16
Baden State	10	31	34
Prussian State	19	50	13
Italian State	104	156	84
St. Polten — Mariagen	63	68	11
Rhaetian Mountain	46	48	11
Bernese Alps	52	55	16
PRINCIPAL TERMINAL OR PASSENGER SERVICE			
New York Central	50	240	47
Pennsylvania	15	72	35
Long Island	100	250	
West Jersey & Seashore	75	150	
N. Y., Westchester & Boston	19	63	
Southern Pacific	50	100	
Metropolitan Railway, London	33	70	20
London, Brighton & South Coast	60	160	
Paris — Orleans	14	46	11
Hamburg — Ohlsdorf	17	41	
MAIN LINE ELECTRIFICATION. 1914–15			
Norfolk & Western	30	85	25
Pennsylvania	20	90	
Canadian Pacific	30	43	4
Chicago, Milwaukee & Puget Sound	113	168	14
North Eastern of England	18	44	10
Swiss Federal	93	100	20
Swedish State	80	93	13
Prussian State	81	124	44
Vienna — Pressburg	42	50	16
Italian State	32	60	81

TABLE VI. STATISTICS OF ELECTRIFICATION

Standard Railways, as compiled by E. P. Burch for "Electric Motive Power in the Operation of Railroads." E. H. McHenry, Vice-President, New York, New Haven & Hartford R. R. Co. 1915.

NAME OF RAILROAD	LINE MILEAGE	TRACK MILEAGE	
Pennsylvania R. R.			
Long Island R. R.	100	250	
New York Terminal	24	100	
West Jersey & Seashore	75	150	
Philadelphia to Paoli	20	90	
	219	590	
New York, New Haven & Hartford R. R.	110	572	
New York Central & H. R. R. R.	50	250	
Chicago, Milwaukee & St. Paul R. R.	113	168	
Southern Pacific R. R.	138	235	
Norfolk & Western Ry.	30	85	
Spokane & Inland Empire Ry.	152	162	
Butte, Anaconda & Pacific Ry.	30	90	
Illinois Traction Railways	200	450	
Michigan & Chicago Ry.	92	100	
Toledo & Western Ry.	59	89	
Ft. Dodge, Des Moines & Southern Ry.	120	126	
Waterloo, Cedar Falls & Northern Ry.	50	100	
Oregon Electric Ry.	154	180	
Portland, Eugene & Eastern Ry.	95	100	
United Railways of Oregon	28	35	
Oakland, Antioch & Eastern Ry.	100	100	
Piedmont & Northern Ry.	140	160	
Boston & Maine R. R.	8	22	Hoosac Tunnel
Baltimore & Ohio R. R.	4	10	Baltimore Tunnel
Michigan Central R. R.	6	20	Detroit Tunnel
Great Northern Ry.	4	6	Cascade Tunnel
Grand Trunk Ry.	4	12	St. Clair Tunnel
Total for United States	1,906	3,662	

EUROPE

COUNTRY	LINE MILEAGE	TRACK MILEAGE	
England	194	521	Including Metropolitan System
France	321	546	
Austria-Hungary	272	362	
Italy	204	364	
Switzerland	204	261	
Germany	146	192	
Sweden	86	96	
Norway	66	78	
Total for Europe	1,493	2,420	

RECAPITULATION

United States	1,906	3,662	
Europe	1,493	2,420	
Canada	45	60	
Australia	150	323	
Grand Total	3,594	6,465	

APPENDIX II

Locomotive Statistics

Notes and Tables I to XXI

I. Distribution of Locomotives as to Service

Year	Freight	Passenger	Unclassified	Switching	Total
1890	16,195	8,499	1,342	4,104	30,140
1900	21,596	9,863	583	5,621	37,663
1910	34,992	13,660	1,180	9,115	58,947
1911	36,405	14,301	1,297	9,324	61,327
1912	37,157	14,263	1,311	9,529	62,262
1913	37,924	14,396	1,224	9,834	63,378
1914	38,752	14,612	1,315	10,081	64,760
Increase 1890 to 1914	22,557 or 139 per cent.	6,113 or 72 per cent.	Decrease 27, or 2 per cent.	5,977 or 145 per cent.	34,620 or 114 per cent.

ANNUAL INCREASE

To 1900	540	136	Dec. 75	151	752
1910	1,339	379	59	349	2,128
1911	1,413	641	117	209	2,380
1912	754	Dec. 38	14	205	935
1913	765	133	Dec. 87	305	1,116
1914	828	216	91	247	1,382

II. Annual Locomotive Mileage — 1890 to 1914

Year	Freight	Passenger	Mixed	Special	Switching	Total Revenue Mileage	Non-Revenue Mileage
1890	435,170,812	285,575,804					
1900	492,568,486	363,521,596					
1910	722,807,242	567,038,846	37,004,818	1,763,935	316,637,057	1,645,251,898	69,185,952
1911	713,640,677	590,164,503	37,432,319	1,702,591	312,912,779	1,655,927,702	64,973,419
1912	702,570,174	606,029,953	38,213,498	1,631,478	317,906,742	1,666,351,845	63,640,173
1913	740,728,063	613,567,550	34,008,000	1,612,978	346,343,886	1,736,371,567	72,343,178
1914	695,276,668	623,090,103	33,767,184	1,312,782	336,187,276	1,689,747,878	66,224,447

Locomotive mileage distinct from Train mileage after 1900. Switching mileage estimated.

III. Average Annual Mileage per Locomotive

Year	Freight	Passenger	Unclassified	Switching	Total Revenue	Switching Excluded
1890	26,870	33,800				
1900	22,808	36,857				
1910	20,656	41,510	28,888	34,738	27,914	26,661
1911	19,603	41,267	30,173	33,559	27,000	26,210
1912	18,907	42,489	30,392	33,372	26,757	25,580
1913	19,531	42,620	29,102	35,219	27,397	25,773
1914	17,941	42,642	26,676	33,368	26,090	24,755
1910 to 1914	Dec. 2,715 or 13.1 per cent.	Inc. 1,132 or 2.7 per cent.	Dec. 2,212 or 7.6 per cent.	Dec. 1,370 or 3.9 per cent.	Dec. 1,824 or 6.5 per cent.	Dec. 1,906 or 7.1 per cent.

IV. Locomotive Mileage in Traffic Districts — 1911 and 1914

District	Freight	Passenger	Mixed	Special	Switching	Total Revenue	Non-Revenue
1911							
Eastern .	328,767,114	258,364,535	7,086,948	753,567	168,499,239	763,471,403	30,384,273
Southern	128,539,367	87,956,285	8,308,630	305,716	45,655,775	270,796,921	8,182,802
Western .	256,334,196	243,843,683	22,036,741	643,308	98,757,765	621,659,378	26,406,344
Total .	713,640,677	590,164,503	37,432,319	1,702,591	312,912,779	1,655,927,702	64,973,419
1914							
Eastern .	314,941,542	263,207,994	6,171,276	584,836	182,183,513	767,089,161	29,747,048
Southern	133,500,025	99,405,763	6,332,067	206,368	49,902,876	289,460,964	9,432,834
Western .	246,835,101	260,476,346	21,263,841	521,578	104,100,887	633,197,753	27,044,565
Total .	695,276,668	623,090,103	33,767,184	1,312,782	336,187,276	1,689,747,878	66,224,447
Increase or Decrease. 1911–1914							
Eastern .	Decrease 13,825,572	Increase 4,843,459	Decrease 915,672	Decrease 168,731	Increase 13,684,274	Increase 3,617,758	Decrease 637,225
Southern	Increase 4,960,658	11,449,478	1,976,563	99,348	4,247,101	18,664,043	Increase 1,250,032
Western .	Decrease 9,499,095	16,632,663	772,900	121,730	5,343,122	11,538,375	638,221
Total .	Decrease 18,364,009	32,925,600	3,665,135	389,809	23,274,497	33,820,176	Increase 1,251,028

PERCENTAGE OF CHANGE. 1911-1914

Eastern .	Dec. 4.2	Inc. 1.8	Dec. 12.9	Dec. 22.4	Inc. 8.1	Inc. 0.4	Dec. 2.9
Southern	Inc. 3.8	Inc. 13.0	Dec. 23.8	Dec. 32.5	Inc. 9.3	Inc. 6.8	Inc. 15.2
Western .	Dec. 3.7	Inc. 6.8	Dec. 3.5	Dec. 18.9	Inc. 5.4	Inc. 1.8	Inc. 2.4
Total .	Dec. 2.5	Inc. 5.5	Dec. 9.8	Dec. 22.9	Inc. 7.4	Inc. 2.4	Inc. 1.9

PERCENTAGE OF DISTRIBUTION OF MILEAGE IN 1914

Eastern .	45.3	42.2	18.3	44.6	54.2	45.4	44.9
Southern	19.2	16.0	18.7	15.7	14.9	17.1	14.2
Western .	35.5	41.8	63.0	39.7	30.9	37.5	40.9
Total .	41.2	37.0	2.0	0.8	19.0		

ANNUAL MILEAGE PER LOCOMOTIVE

District	1911				1914			
	Freight	Passenger	Switching	Total	Freight	Passenger	Switching	Total
Eastern .	20,073	33,033	34,822	28,118	18,070	38,587	36,400	27,023
Southern	22,097	48,248	38,576	28,866	21,449	51,827	34,511	28,525
Western .	18,039	42,892	29,908	29,972	17,629	43,867	29,850	27,502
Total .	19,603	41,267	33,559	27,734	19,114	42,675	34,350	27,960

Total annual mileage includes mixed and special trains and non-revenue mileage.

V. Locomotive Characteristics

Year	Number	Tractive Power Pounds	Grate Surface Square Feet	Heating Surface Square Feet	Weight Without Tender Tons	Weight on Drivers Tons
1908	56,468	1,503,971,444	1,869,639	117,797,587	4,056,733	3,306,613
1914	63,510	1,931,953,982	2,353,139	153,831,859	5,271,123	4,268,336
Increase per cent.	12.4	28.5	25.9	30.6	29.9	29.1

AVERAGE PER LOCOMOTIVE

1908		26,634	35	2,086	72	59
1914		30,419	37	2,422	83	67
Increase		3,785	2	336	11	8

The above statement is exclusive of locomotives of the Mallet type, also of locomotives in the service of switching and terminal companies.

Oil-burning Locomotives, 1911, 3870; 1912, 4052; 1913, 4055; 1914, 4140.

VI. Comparative Use of Compound Locomotives

Year	Single Expansion	Two-Cylinder Compound	Four-Cylinder Compound	Unclassified	Total
1910	55,867	862	1,511	707	58,947
1911	57,963	796	1,838	730	61,327
1912	58,842	751	1,951	718	62,262
1913	60,131	707	2,040	450	63,378
1914	61,518	659	2,108	475	64,760
1910 to 1914	Inc. 5,651	Dec. 203	Inc. 597	Dec. 232	Inc. 5,813

MALLET TYPE INCLUDED IN ABOVE

1910		0	200		200
1911		4	431		435
1912		1	533		534
1913			717		717
1914			775		775
Increase 1910 to 1914			575		575

VII. Distribution of Motive Power in Territorial Traffic Districts — 1914

District	Locomotive Classification						Total Tractive Power Except Unclassified	
	Freight	Passenger	Unclassified	Switching	Total		Pounds	Per cent.
					No.	Per cent.		
Eastern .	17,429	6,821	232	5,005	29,487	45.6	927,441,203	46.5
Southern	6,224	1,918	890	1,446	10,478	16.1	318,986,258	16.0
Western	15,099	5,873	193	3,630	24,795	38.3	740,767,139	37.5
Total .	38,752	14,612	1,315	10,081	64,760	100.0	1,987,194,600	100.0

VIII. Locomotives of Mallet Type, Included in Table VII

District	Number	Per cent.	Tractive Power		
			Pounds	Per cent.	Average
Eastern .	100	12.9	8,833,762	14.4	88,337
Southern .	200	25.8	15,770,300	25.8	78,851
Western .	475	61.3	36,636,656	59.8	77,129
Total .	775	100.0	61,240,718	100.0	79,033

IX. Distribution of Motive Power per 1000 Miles of Line

District	Freight	Passenger	Switching	Unclassified	Total	Tractive Power Pounds
Eastern . . .	276	108	79	4	467	14,281,289
Southern . .	133	41	31	19	224	7,843,289
Western . . .	110	43	26	1	180	5,261,301
Total . . .	157	59	41	5	262	7,769,315

X. Motive Power Efficiency on Railroads with over 500 Locomotives

I. C. C. Report for 1914

EASTERN DISTRICT

Railroads	Single Expansion		Four-Cylinder Compound		Two-Cylinder Compound		Total	
	No.	Tractive Power	No.	Power	No.	Power	No.	Power
Pennsylvania .	3,806	134,627,802	4	235,001			3,810 [1]	134,862,803
N. Y. Central .	2,461	79,611,700	31	2,188,300	43	1,790,000	2,535 [2]	83,590,000
Balt. & Ohio . .	2,320	83,363,912	32	3,279,785			2,352 [3]	86,643,697
N. Y., N. H. & H.	1,198	28,902,921			6	171,390	1,204 [4]	29,074,311
Pennsylvania Co.	1,432	50,280,422	2	49,966			1,434	50,330,388
L. S. & M. S. .	993	34,725,620	3	317,000			996	35,042,620
Erie	1,310	44,893,029	16	715,730			1,326	45,608,759
Boston & Maine	1,193	29,176,900			10	303,600	1,203 [5]	29,480,500
Phila. & Reading	1,005	30,122,463					1,005	30,122,463
P., C., C. & St. L.	792	25,136,806					792	25,136,806
Del., L. & W. .	761	23,319,014					761	23,319,014
Lehigh Valley .	947	30,222,600					947	30,222,600
C., C., C. & St. L.	865	29,441,140					865	29,441,140
Mich. Central .	650	20,119,554			99	3,833,400	749 [6]	23,952,954
Wabash . . .	669	18,689,247			32	691,556	701	19,380,803
Central of N. J.	523	13,955,778					523	13,955,778
Total . .	20,925	676,588,908	88	6,785,782	190	6,789,946	21,203	690,164,636

SOUTHERN DISTRICT

Railroads	Single Expansion No.	Tractive Power	Four-Cylinder No.	Power	Two-Cylinder No.	Power	Total No.	Power
Southern . . .	1,625	52,915,700	2	161,000			1,627	53,076,700
Illinois Central .	1,448	43,893,767					1,448	43,893,767
L. & N. . . .	1,036	31,296,486					1,036	31,296,486
N. & W. . . .	957	33,413,862	90	6,690,000	10	403,040	1,057	40,506,902
A. C. L. . . .	813	18,427,430	1	4,300			814	18,431,730
C. & O. . . .	728	26,202,755	77	6,203,560	20	513,626	825	32,919,941
S. A. L. . . .	525	14,382,596					525	14,382,596
Total . .	7,132	220,532,596	170	13,058,860	30	916,666	7,332	234,508,122

[1] Also 68 Electric Tractors.
[2] Also 62 Electric Tractors.
[3] Also 13 Electric Tractors.
[4] Also 104 Electric Tractors.
[5] Also 58 Electric Tractors.
[6] Also 6 Electric Tractors.

X. Motive Power Efficiency on Railroads with over 500 Locomotives — *Continued*

WESTERN DISTRICT

Railroads	Single Expansion		Four-Cylinder Compound		Two-Cylinder Compound		Total	
	No.	Tractive Power	No.	Power	No.	Power	No.	Power
A., T. & S. F.	1,045	29,157,022	795	33,170,700			1,840	62,327,722
C., B. & Q.	1,724	50,388,320	49	2,001,600			1,773	52,389,920
So. Pacific	1,235	38,045,471	85	6,076,230	22	794,230	1,342 [1]	44,915,931
C., M. & St. P.	1,700	49,103,503	269	8,396,080			1,969	57,499,583
C. & N. W.	1,830	49,995,660					1,830	49,995,660
Grt. Northern	1,179	39,191,028	138	9,458,150			1,317 [2]	48,649,178
No. Pacific	1,090	35,511,040	86	4,426,100	181	5,459,800	1,357	45,396,940
C., R. I. & P.	1,614	47,287,939	8	192,000			1,622	47,479,939
Union Pac.	694	23,359,449	109	3,556,450			803	26,915,899
St. L.-S. F.	944	26,729,400	27	1,168,500	4	106,400	975	28,004,300
St. L., I. M. & So.	584	17,113,990	1	94,400			585	17,208,390
M., K. & T.	654	18,655,067	2	46,800			656	18,701,867
M., St. P. & S. Ste M.	380	9,960,302			158	4,604,485	538	14,564,787
Mo. Pac.	605	17,466,503					605	17,466,503
D. & R. G.	593	16,706,314	24	1,991,088			617	18,697,402
Total	15,871	468,671,008	1,593	70,578,098	365	10,964,915	17,929	550,214,021

UNITED STATES

Eastern Dist.	20,925	676,588,908	88	6,785,782	190	6,789,946	21,203 [3]	690,164,636
Southern Dist.	7,132	220,532,596	170	13,058,860	30	916,666	7,332	234,508,122
Western Dist.	15,871	468,671,008	1,593	70,578,098	365	10,964,915	17,829 [4]	550,214,021
Total	43,928	1,365,792,512	1,851	90,422,740	585	18,671,527	46,364	1,474,886,779

[1] 1 Electric Tractor.
[2] 4 Electric Tractors.
[3] 258 Electric Tractors.
[4] 5 Electric Tractors.

XI. Roads Operating Articulated Locomotives with Total Tractive Power in Excess of 1,000,000 Pounds

Name of Road	Number	Tractive Power, Pounds
Great Northern	128	9,231,850
Norfolk & Western	90	6,690,000
Chesapeake & Ohio	77	6,203,560
Atchison, Topeka & Santa Fé	83	6,084,900
Southern Pacific	61	5,537,960
Baltimore & Ohio	32	3,279,785
Chicago, Milwaukee & St. Paul	41	3,124,200
Northern Pacific	37	2,771,100
New York Central	31	2,188,300
Denver & Rio Grande	24	1,991,088
Virginian	19	1,790,500
Delaware & Hudson	13	1,369,500
Chicago, Burlington & Quincy	19	1,362,000
Total	655	51,624,843

Per cent. in United States of number of articulated locomotives 84
Per cent. in United States of tractive power of articulated locomotives . . . 87

XII. Locomotives Classified as to Variations in Wheel Arrangement

Class	Front Wheels	Driving Wheels	Rear Wheels	1911	1912	1913	1914	Total for Each Year			
								1911	1912	1913	1914
A	0	4	0	610	564	519	477				
	0	6	0	7,026	7,215	7,563	7,703				
	0	8	0	264	263	273	293				
	0	10	0	24	23	23	23				
	0	12	0		12	5		7,924	8,077	8,383	8,496
B	2	4	0	16	15	7	3				
	2	6	0	5,561	5,402	5,154	5,013				
	2	8	0	19,213	19,456	19,718	20,227				
	2	10	0	30	30	25	25	24,820	24,903	24,904	25,268
C	4	4	0	8,692	8,299	7,539	7,157				
	4	6	0	11,081	11,031	10,930	10,812				
	4	8	0	810	839	796	733	20,583	20,169	19,265	18,702
D	0	4	2	13	11	9	12				
	0	6	2	9	8	6	9	22	19	15	21
E	2	4	2	18	12	7	9				
	2	6	2	1,516	1,507	1,516	1,477				
	2	8	2	671	1,159	1,159	3,237				
	2	10	2	150	156	156	188	2,355	2,834	2,838	4,911
F	4	2	2	1	1	1	1				
	4	4	2	2,011	2,146	2,022	2,079				
	4	6	2	2,240	2,702	3,355	3,875				
	4	8	2	2	3	3	25	4,254	4,852	5,381	5,980
G	0	4	4	47	49	25	19				
	0	6	4	3		1	1	50	49	26	20
H	2	2	4		1	1	2				
	2	4	4	58	58	51	51				
	2	6	4	60	12	25	23	118	71	77	76
I	4	2	4	1	1	1	1				
	4	6	4	7	7	7	7	8	8	8	8
K	2	4	6	10	10	10	10				
	2	6	6	18	18	18	18	28	28	28	28
Total								60,162	61,010	60,925	63,510

ARTICULATED OR MALLET LOCOMOTIVES

Class	Front Wheels	Driving Wheels	Rear Wheels	1911	1912	1913	1914	1911	1912	1913	1914
A	0	12	0	13	11	19	16				
	0	16	0	24	41	46	59	37	52	65	75
B	2	12	0	12	15	21	25				
	2	14	0	40	40	41	40				
	2	16	0	4	4	29	29	56	59	91	94
E	2	10	2	2	2	2	2				
	2	12	2	279	345	433	464				
	2	16	2	51	66	115	118				
	2	20	2	10	10	10	10	342	423	560	594
F	4	12	2			1	12			1	12
Total								435	534	717	775

XIII. VARIATIONS IN WHEEL ARRANGEMENT AND NOMENCLATURE OF TYPES

Compiled from Whyte's Classification, Locomotive Dictionary, 1912, and from reports of Interstate Commerce Commission.

CLASS	FRONT WHEELS	DRIVING WHEELS	REAR WHEELS	TYPE	
A	0	4	0	Switcher	
A	0	6	0	Switcher	
A	0	8	0	Pusher	
A	0	10	0	Pusher	
A	0	12	0	Pusher	
B	2	4	0	Early type	
B	2	6	0	Mogul	
B	2	8	0	Consolidated	
B	2	10	0	Decapod	
B	2	12	0	Centipede	
C	4[1]	4	0	American	
C	4[1]	6	0	Ten-wheeler	
C	4[1]	8	0	Twelve-wheeler	
C	4[1]	10	0	Mastodon	
D	0	4	2	Experimental	
D	0	6	2	Experimental	
E	2	4	2	Columbia	
E	2	6	2	Prairie	Designed for Chicago Burlington & Quincy R. R. Co.
E	2	8	2	Mikado	Designed in 1895 for Japan Railway
E	2	10	2	Santa Fé	Designed in 1903 for A., T. & S. F. Ry.
F	4[1]	2	2	Single Driver	Obsolete
F	4[1]	4	2	Atlantic	Designed in 1895 for Atlantic Coast Line
F	4[1]	6	2	Pacific	Designed in 1901 for New Zealand Government Railways.
F	4[1]	8	2	Mountain	
G	0	4	4[1]	Forney	
G	0	6	4[1]	Forney	
H	2	2	4[1]	Experimental	
H	2	4	4[1]	Experimental	
I	4[1]	2	4[1]	Experimental	
I	4[1]	6	4[1]	Experimental	
K	2	4	6[1]	Experimental	
K	2	6	6[1]	Experimental	
		ARTICULATED OR MALLET LOCOMOTIVES			
A	0	6–6	0	Mallet	
A	0	8–8	0	Mallet	
B	2	6–6	0	Mallet	
B	2	6–8	0	Mallet	
B	2	8–8	0	Mallet	
E	2	4–6	2	Mallet	
E	2	6–6	2	Mallet	
E	2	8–8	2	Mallet	
E	2	8–8–8	2	Mallet	
E	2	10–10	2	Mallet	
F	4[1]	6–6	2	Mallet	

XIV. Dimensions and Performance of High-speed Locomotives

International Railway Congress of 1910. William Garstang

	Atlantic Type, — Five Designs	Pacific Type, — Two Designs
Boilers. Square feet of heating surface.		
Total	2640–3335	4141–4242
Tubes	2474–3141	3960–4000
Working pressure in pounds	180–210	200
Cylinders. Diameter in inches	20–22	22
Stroke in inches	26	28
Wheels. Diameter in inches. Driving	78–80	79
Leading	36	36
Trailing	48–50	50
Weight in tons. Working order	90–95	131–133
On driving wheels	48–59	86
Rigid wheel-base — feet	7′–7½″	14
Tractive power — pounds	21,400–27,400	29,900
Ratio. Total heating surface to grate area. Square feet	47.56–66.3 to 1.00	73.–75.2 to 1.00
Sq. ft. of heating surface to cylinder-volume in cubic feet	305–632 to 1	340–344 to 1
Theoretical tractive power to adhesion-weight	0.992–1.32 to 1.00	0.74–1.15 to 1.00
Weight of train, less locomotive — tons	300–399	380–524
Number of cars in train (passenger)	5–7	6–9
Schedule speed (miles per hour) on divisions of 50 miles and over	52–61	55–70
Greatest speed to maintain schedule (miles per hour)	70–90	75–80
Miles run without stop	60–148	148–182
Miles run without change	130–206	148–182
Average yearly mileage	60,440–105,600	60,000–90,000

XV. Motive Power Efficiency

Based on Interstate Commerce Commission Report for 1914

CLASS I. ROADS WITH ANNUAL OPERATING REVENUES ABOVE $1,000,000

	United States	Eastern District	Southern District	Western District
	LOCOMOTIVES IN REGULAR SERVICE			
Freight	37,405	17,053	5,923	14,429
Passenger	14,090	6,618	1,806	5,666
	REVENUE LOCOMOTIVE MILEAGE			
Freight	678,776,684	308,922,938	130,293,576	239,560,170
Passenger	601,322,506	254,408,624	94,709,044	252,204,838
	ANNUAL MILEAGE			
Freight	18,146	18,115	22,000	16,603
Passenger	42,677	38,442	52,441	44,512
	DAILY MILEAGE			
Freight	49.7	49.9	60.3	42.8
Passenger	117.9	105.3	143.6	122.0
	HOURS ON THE ROAD			
Freight	3.82	3.84	4.64	3.30
Passenger	4.07	3.63	4.95	4.21
	PERCENTAGE OF DISTRIBUTION AS TO SERVICE			
Freight	60 per cent.	59 per cent.	60 per cent.	61 per cent.
Passenger	22 per cent.	23 per cent.	18 per cent.	24 per cent.
Other	18 per cent.	18 per cent.	22 per cent.	15 per cent.

Mileage estimated at 13 miles per hour for freight-locomotives, and 29 miles per hour for passenger-locomotives, including all delays and stops between terminals.

XVI. Electric Tractor Dimensions and Performance

Norfolk & Western Railway

PRINCIPAL DIMENSIONS OF ELECTRIC TRACTORS

Driving wheels — 62″ diam.
Weight on drivers, 220 tons.
Rigid wheel-base, 11′–0″.
Length over all, 105′–8″.
Truck wheels — 30″ diam.
Total weight, 270 tons.
Total wheel-base, 83′–10″.

EIGHT THREE-PHASE INDUCTION MOTORS

Rating at	18 miles per hour	28 miles per hour
Maximum acceleration	4,500 h.p.	6,400 h.p.
One-hour rating	3,300 "	3,300 "
Continuous rating	2,600 "	3,000 "
Maximum accelerating tractive effort	125,000 lb.	90,000 lb.
For one hour	87,000 "	44,000 "
Continuously	68,000 "	40,000 "

TRAFFIC STATISTICS

Coal trains eastward, daily	20
Freight and passenger trains helped daily	6
Coal tonnage eastward, daily	65,000 tons

WEIGHT OF TRAIN, LESS TRACTORS

Up 1.5 per cent and 2.0 per cent grades	3,250 tons
On other grades	4,700 tons

OPERATING SPEED

On heavy grades, 14 miles per hour.
On light grades, 28 miles per hour.

Time of average round-trip of 58 miles	6 hours
Time of average round-trip, steam locomotives	12 hours

Number of electric tractors	12
Number of Mallet locomotives displaced	34

Loaded coal trains handled by one tractor at head and one at rear.
Steam freight and heavy passenger trains assisted by electric pusher.

XVII. Electric Tractor Dimensions and Performance

Chicago, Milwaukee & St. Paul Railway

PRINCIPAL DIMENSIONS OF ELECTRIC TRACTORS

Tractors in coupled pair.

Total weight	260 tons
Weight on drivers	200 "
Number of driving axles and motors	8
Number of four-wheel trucks	2
Total length	112 feet
Rigid wheel-base	10 "
Voltage of tractor	3,000 volts
Voltage per motor	1,500 "
Rating per motor, one hour	430 h.p.
Rating per motor, continuous	375 "
Rating of tractor, one hour	3,440 "
Rating of tractor, continuous	3,000 "
Trailing load, two per cent. grade	1,250 tons
Trailing load, one per cent. grade	2,500 "
Approximate speed under these conditions	16 miles per hour
Tractive effort at starting with 30 per cent. coefficient of adhesion	120,000 lb.
Tractive effort continuously	72,000 "

XVIII. Formulas for Tractive Power of Locomotives

The tractive power of a locomotive depends upon the size of its cylinders, steam-pressure, length of stroke, diameter of driving-wheels, and the weight resting upon them which produces adhesion or resistance to slipping.

The power exerted on the piston is applied through the connecting-rods to the crank-pin of the driving-wheel, the distance from axle-center to crank-pin being one half of the stroke.

The maximum effect is that of a third-class lever with fulcrum at the center of the axle, the power at center of crank-pin, and the resistance at end of radius perpendicular to the rail. This maximum effect is reached at half-stroke, the power at the beginning and end of stroke ("dead-centers") being zero. As the crank-pin on one driving-wheel is set 90° in advance of its opposite on same axle, one cylinder balances the other when both are working, and the maximum tractive effort is constant.

Up to the slipping limit, the adhesion between wheel and rail makes rolling possible and converts the crank-pin into a lever, whereby the entire push or pull at the crank-pin, made effective at the rim of the wheel, is transmuted into equivalent draw-bar pull, less the machinery-resistance and the rolling-friction of locomotive and tender.

The energy developed in each cylinder of the locomotive is expressed by the formula

$$E = C^2 \times P \times 0.85\frac{\pi}{4} = C^2 \times P \times 0.67$$

E = energy in pounds,
C = diameter of cylinders in inches,
P = boiler pressure in pounds,
$\pi = 3.1415926+$

The energy, E, multiplied by the distance between axle and crank-pin centers $\left(= \text{half-stroke or } \frac{S}{2}\right)$ is equal to tractive effort, T, multiplied by radius, R ($= \frac{1}{2}$ diameter, D);

$$\frac{ES}{2} = TR; \quad T = \frac{ES}{2R} = \frac{ES}{D}.$$

As before stated, this energy is made wholly effective only at half-stroke, so in order to make it constant, both cylinders must be working.

The formula for simple engines becomes, therefore,

$$T = \frac{0.67\, PC^2S}{D} \text{ or } \frac{PS}{D}(0.67\, C^2),$$

based on taking steam-pressure in the cylinders at 85% of the boiler-pressure.

According to this formula, the conventional "standard locomotive" of 25,000 lb. tractive power, as unit of comparison, would be represented by a locomotive with cylinders 21 inches in diameter and 26 inches stroke, with effective steam-pressure in cylinders of 170 lb. (or 85 per cent. of 200 lb. boiler-pressure) per square inch, and driving-wheels 60 inches in diameter.

The formula for four-cylinder balanced compound engines, in which C_1 is the diameter of the high-pressure cylinder and C_2 the diameter of the low-pressure cylinder is

$$T = \frac{PS}{D}(0.67C_1^2 + 0.25C_2^2).$$

The low-pressure cylinder having something over double the piston-area of the high-pressure cylinder, the initial steam-pressure received from the high-pressure cylinder is reduced one-half or more, and a further reduction of work done is due to using the steam expansively; so that in the above formula approximately one quarter of the low-pressure cylinder area ($0.25C_2^2$) is added to the high-pressure cylinder factor.

In the case of the articulated compound or Mallet engines, with four cylinders, taking the low-pressure cylinder area as 2.36 times that of the high-pressure cylinder, the above formula becomes

$$T=\frac{PS}{D}(0.67C_1^2+2.36C_1^2\times0.25),$$

$$\text{or}\quad T=\frac{PS}{D}(1.26C_1^2).$$

The Coefficient of Adhesion is virtually constant at all speeds. On a straight and level track, it varies with the condition of the surface of the rails.

Coefficient of Adhesion

("Railway Location," Wellington, p. 437)

Wheel Load Exceeding 10,000 lb.	*Per Cent. of Maximum Load on Driving-wheels*
Ultimate Limit	0.35 to 0.37
Working Limit	
with sand	$\frac{1}{3}$ or 0.33
in ordinary weather	$\frac{1}{4}$ or 0.25
on slightly moist or frosty rail	$\frac{1}{5}$ or 0.20
after wheels have once slipped	$\frac{1}{10}$ or 0.10

Tractive power, as applied in train-service, is considered effective where the tender is coupled. to the train. Therefore, from the power developed within the limit of adhesion, a reduction is made for the resistance to be overcome in the locomotive and tender. It is customary with locomotive-builders to estimate the machinery-resistance at 22.2 lb. per ton-weight on the driving-wheels and the rolling-resistance of the locomotive and tender at 4 lb. per ton.

Example

Dimensions of locomotive. Cylinders, 21 by 26 inches; Driving-wheels, 60 in. diameter; Boiler-pressure, 200 lb. per sq. in.

Tractive power:

$$\frac{PS}{D}(0.67C^2)=200\times\frac{26}{60}(0.67\times21^2)=25{,}607\text{ lb.}$$

Weight of locomotive on driving-wheels	115,000 lb.
Weight on forward truck	43,000 "
Total weight of locomotive	158,000 "
Weight of tender, loaded	97,000 "
Total weight of locomotive and tender	255,000 "
Weight available within limit of adhesion, 0.25 of weight on driving-wheels	28,750 "
Actual tractive power at rim of driving-wheels	25,607 "
Resistance of machinery, per ton	22.2 "
Rolling-resistance of locomotive and tender, per ton	4.0 "
Machinery-resistance, $\frac{115{,}000}{2{,}000}=57.5$ tons $\times$ 22.2 lb.	1,276 "

Rolling-resistance, $\frac{855,000}{2,000} = 127.5$ tons $\times$ 4 lb. . . . . 510 lb.

Total resistance of locomotive and tender . . . . 1,786 "

Tender draw-bar pull, 25,607 − 1,786 . . . . 23,821 "

Assuming the resistance of a loaded car at a speed of 10 miles an hour as 4.65 lb. per ton, then $\frac{23,821}{4.65} = 5,123$ tons as the gross train-weight for such a locomotive on straight and level track.

XIX. Early Locomotives

As mentioned in Chapter III, on Motive Power, page 37, the essential features of a locomotive, considered as a steam-generator, are the multi-tubular boiler and the forced draft created or induced by exhausting the steam from the cylinders into the smoke-box and through the stack.

The principles of both of these inventions were applied independently in Peter Cooper's experimental locomotive, "Tom Thumb," which was tested on the Baltimore & Ohio R. R. on August 28, 1830, only ten months after the trial of the "Rocket" at Rainhill. It weighed but one ton and the cylinder was 3½ inches in diameter.

The "Stourbridge Lion," built by Foster, Rastrack & Co. of Stourbridge, arrived in New York in 1829, together with two Stephenson locomotives. These locomotives had been purchased for the Delaware & Hudson Coal Co. by Horatio Allen, its Chief Engineer. The "Stourbridge Lion" had a flue-boiler and weighed seven tons. It was found to be too heavy for the track and was never in regular service, and the Stephenson locomotives, for the same reason, were not taken from New York.

Mr. Allen afterward designed the "Best Friend," which was built at the West Point Foundry and made a trial trip on November 2, 1830, at Charleston, S. C., upon the Charleston & Hamburg R. R. (subsequently merged in the South Carolina R. R. Co.), and shortly afterward exploded.

On August 9, 1831, the first train passed over the Mohawk & Hudson R. R. from Albany to Schenectady, drawn by the "De Witt Clinton," built at the West Point Foundry from plans by John B. Jervis, Chief Engineer of the road. This locomotive, the third built in the United States, weighed 6758 lb., with cylinders 5½ by 16 in.; four wooden driving-wheels, 4 ft. 6 in. in diam.; boiler-capacity, 115 gal.; working-pressure, 50½ lb.

Two weeks later, the "Robert Fulton," built by Stephenson, was put in service on the same road. It weighed 12,742 lb., and was unable to draw a gross weight of twelve tons.

In 1831, the maximum weight of locomotives on the Baltimore & Ohio R. R. was officially fixed at 3½ tons, with tractive power sufficient to draw 15 tons on a level road.

The "Old Ironsides," built by M. W. Baldwin in 1832 for the Germantown & Norristown R. R. Co., had wooden driving-wheels with cast-iron hubs and weighed 5 tons. It was the first successful locomotive built in this country.

In 1840, locomotives on the Philadelphia & Reading R. R. weighed 12 tons.

(See "When Railroads Were New," C. F. Carter; and "Pioneer Railway Development in the United States," W. D. Taylor. Transactions Am. Soc. Civil Engineers, December, 1911.)

XX. General Distribution of Heat in a Locomotive Boiler

	Per Cent.
Loss in ash-pan	5.3
Loss in smoke-box	18.0
Heat through boiler-surface (with superheater)	76.7

Distribution of Heat in the Steam Product

Loss by radiation	3.5
Loss in machinery-friction	1.0
Useful work at drawbar	7.0
Heat discharged in exhaust-steam	65.2
As above	76.7

Locomotive with 76 sq. ft. of grate-area, burning 60 lb. of anthracite coal per square foot per hour; coal of 14,000 British thermal units per pound heat-value.

	B. T. U. Per Hour
Total heat available in the coal	63,840,000
Boiler-efficiency, 76.7 per cent.	48,965,280
Heat in steam going into cylinders, less loss by radiation	46,092,480

Evaporating about 36,000 lb. of feed-water per hour at 60° F.

Discharged up the stack, per hour	11,461,200
Discharged in exhaust-steam	41,623,680
83.2 per cent. of total heat in coal	53,084,880

George M. Basford. Journal Am. Soc. Mechanical Engineers, September, 1917.

XXI. Pulverized Fuel

In a modern locomotive, only from 45 to 70 per cent. of the heat produced from the fuel consumed is absorbed by the boiler. In addition to the loss in smoke-box gases, there is a waste from incomplete combustion in sparks, cinders and ashes. The loss in unburnt or incompletely burnt fuel is due to the deficient exposure to the action of oxygen of the hydro-carbon element in the lumps of coal. By breaking up these lumps into dry, minute and uniform particles, it becomes possible to burn all of the available combustible elements in the fuel.

The pulverized fuel in the inclosed tender-space gravitates to the conveyor-screws which carry it to the fuel and air-pressure feeders, where it commingles with the air. It is then blown through the connecting-hose to the fuel and air-delivery nozzles, and into the burners. The mixture is drawn by the front-end draft into the furnace, where complete combustion of the fuel in suspension takes place. The liquid ash is precipitated into the self-cleaning ash-pan, where it solidifies into a mass that can be readily dumped. The blower is driven by a constant-speed steam-turbine which requires neither regulation nor control. The conveyors, feeders and comminglers are driven by a variable-speed steam-turbine which is controlled by the fireman.

The boiler filled with cold water may be brought under maximum steam-pressure within an hour and the fuel-feed then stopped until the locomotive is called for service. The feed can also be stopped while standing at terminals or drifting on the road. After the day's work the locomotive can be immediately housed without the usual ash-pit delay.

John E. Muhlfeld, Journal Am. Soc. Mechanical Engineers. September, 1917.

APPENDIX III

Rolling-Stock Statistics

Tables I to XI

(Cars of private corporations and industries excluded)
Computed from Reports of Interstate Commerce Commission

I. Distribution and Increase of Equipment as to Traffic

Year	Passenger Service	Freight Service	Company's Service	Total	Annual Increase			
					Passenger	Freight	Company	Total
1889	24,586	1,013,960	31,020	1,069,566				
1890	26,820	1,109,952	32,895	1,169,667	2,234	95,992	1,875	100,101
1900	34,713	1,365,531	50,594	1,450,838	789	25,558	1,770	28,117
1910	47,095	2,135,121	108,115	2,290,331	1,238	76,959	5,752	83,949
1911	49,818	2,195,511	114,006	2,359,335	2,723	60,390	5,891	69,004
1912	51,490	2,215,549	115,635	2,382,674	1,672	20,038	1,629	23,339
1913	51,700	2,273,564	120,244	2,445,508	210	58,015	4,609	62,834
1914	53,466	2,325,647	124,709	2,503,822	1,766	52,083	4,465	58,314

II. Classification of Freight Equipment

Year	Box	Flat	Stock	Coal	Tank	Refrigerator	Other	Total
1905	802,964	146,056	62,988	632,171	4,918	26,844	51,685	1,727,620
1906	843,118	146,908	64,202	686,717	5,324	31,782	55,581	1,833,635
1907	904,821	156,859	64,997	746,670	5,972	33,617	68,081	1,986,017
1908	950,209	159,748	76,218	805,185	6,888	27,930	70,055	2,096,234
1909	941,533	154,630	73,494	792,291	6,630	28,204	74,556	2,071,338
1910	966,577	153,918	77,584	818,689	7,434	30,918	78,411	2,133,531
1911	990,313	153,300	77,590	853,699	7,787	31,786	80,856	2,195,331
1912	1,004,005	150,840	76,535	855,111	7,836	30,693	90,219	2,215,239
1913	1,032,585	147,541	78,308	871,339	8,216	43,389	91,911	2,273,289
1914	1,043,796	146,133	82,971	899,314	8,530	48,886	96,017	2,325,647

INCREASE IN FREIGHT EQUIPMENT 1905 TO 1914

Cars	1905	1910	1914	1905 to 1910		1910 to 1914	
				No.	Increase per annum	No.	Increase per annum
Box . . .	802,964	966,577	1,043,796	163,613	32,722	77,219	19,305
Flat . . .	146,056	153,918	146,133	7,862	1,572	Dec. 7,785	Dec. 1,946
Stock . . .	62,988	77,584	82,971	14,596	2,919	5,387	1,346
Coal . . .	632,171	818,689	899,314	186,518	37,303	80,625	20,156
Tank . . .	4,918	7,434	8,530	2,516	503	1,096	274
Refrigerator	26,844	30,918	48,886	4,074	815	17,968	4,492
Other . . .	51,685	78,411	96,017	26,726	5,345	17,606	4,401
Total . .	1,727,620	2,133,531	2,325,647	405,911	81,182	192,116	48,029

Exclusive of cars in Company's service — 124,709 in 1914, and on Fast Freight Lines — 29,149 in 1914.

(Discrepancies in Totals as in Reports.)

III. Classification of Cars as to Capacity (Maximum Load in Pounds)

BOX CARS

Year	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000	110,000	120,000	130,000	150,000	200,000	Total
1905	258	3,343	16,087	139,200	93,961	435,970	9,500	87,484	2	17,159						802,964
1906	216	2,635	10,868	117,122	89,424	466,684	12,018	119,016		25,132						843,115
1907	203	2,226	4,248	94,637	84,098	499,595	14,840	171,020		33,954						904,821
1908	164	1,897	2,471	76,468	74,179	524,265	18,112	206,140		46,513						950,209
1909	185	1,431	1,877	62,147	65,585	529,572	17,827	211,054		51,855						941,533
1910	168	1,307	1,233	51,652	56,079	531,880	17,748	247,693		58,817						966,577
1911	190	1,210	1,006	40,835	47,245	537,998	17,636	278,496		65,697						990,313
1912	183	1,053	2,281	32,460	43,718	536,136	17,156	304,646		66,372						1,004,008
1913	122	854	2,004	26,442	37,264	524,755	18,226	345,950		76,968						1,032,585
1914	116	725	1,719	21,152	30,805	503,636	18,139	376,432		91,072						1,043,796

FLAT CARS

Year	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000	110,000	120,000	130,000	150,000	200,000	Total
1905	643	2,861	5,575	38,191	16,724	46,037	7,462	23,446		5,091	4	10		6		146,050
1906	569	2,217	4,479	34,374	16,096	49,237	7,735	25,784	187	6,202	4	14		9	1	146,908
1907	392	1,918	2,961	29,845	15,362	53,407	9,280	34,125		9,519	23	14		12	1	156,859
1908	266	2,062	2,115	25,950	15,162	54,524	9,553	38,398	299	11,369	23	10	5	11	1	159,748
1909	327	1,784	1,896	22,949	13,946	53,862	9,481	38,671	299	11,385	4	10		15	1	154,630
1910	270	1,651	1,575	19,581	12,519	53,367	10,192	39,743	299	14,691	4	10	9	4	3	153,918
1911	239	1,500	1,459	17,487	11,461	52,423	9,747	42,318		16,634	4	14		10	4	153,300
1912	246	1,503	1,408	15,731	10,349	50,512	10,014	43,013		18,014	4	19		17	10	150,840
1913	80	1,209	926	12,789	8,302	47,710	10,413	44,799		21,166	4	15	10	58	10	147,401
1914	80	1,116	827	10,751	6,974	45,502	10,751	46,113		23,709	4	19	10	177	10	146,043

STOCK CARS

Year	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000	110,000	120,000	130,000	150,000	200,000	Total
1905	73	150	1,538	15,580	12,805	31,544		933		365						62,988
1906	69	105	1,016	13,393	12,148	34,685		2,264		522						64,202
1907	73	99	441	12,571	11,392	37,725		5,876		1,825						70,002
1908	47	87	230	14,399	11,446	40,979		7,277		1,754						76,219
1909	56	69	146	12,293	10,580	40,911		7,568		1,871						73,494
1910	50	71	104	11,468	9,987	44,119		9,501		2,284						77,584
1911	49	69	76	9,154	8,217	46,487		11,104		2,434						77,590
1912	49	61	78	8,740	7,550	45,638		11,976		2,443						76,535
1913	47	43	76	8,452	7,399	45,926		13,189		3,176						78,308
1914	47	39	67	7,909	8,324	45,958		18,251		2,376						82,071

COAL CARS

1905	1,787	905	2,616	78,922	69,701	196,438	6,551	171,719	1,062	101,796	440	34			200	632,171
1906	1,559	735	1,591	67,152	62,961	188,345	6,507	202,842	2,349	151,924	508	44			200	686,717
1907	1,366	601	1,086	56,936	52,485	178,442	6,470	224,821	2,339	220,600	1,290	34			200	746,670
1908	1,175	642	688	23,270	59,524	185,367	8,077	240,769	3,154	279,731	2,544	44			200	805,185
1909	1,047	568	458	18,933	46,842	178,322	7,508	240,794	4,772	289,429	3,574	44				792,291
1910	576	530	341	15,602	34,696	165,160	7,483	310,391	3,220	267,969	12,677	44		(140,000)		818,689
1911	553	531	316	12,748	29,280	155,305	7,969	253,123	3,838	360,651	29,055	44		286		853,699
1912	301	432	298	9,288	23,968	139,918	6,446	250,530	3,833	386,736	33,018	44	298	1	(180,000)	855,111
1913	268	328	292	4,544	20,904	112,140	7,387	251,479	3,818	425,327	44,039	40	298	474	1	871,339
1914	18	277	239	3,602	16,163	87,858	6,062	248,139	3,808	474,376	54,277	32	298	3,435	750	899,334

TANK CARS

1905	3	482	117	152	106	1,066	25	1,483	1	1,483						4,918
1906	1	478	112	225	156	1,140	80	1,489	1	1,642						5,324
1907		478	117	397	144	1,100	125	1,840		1,771						5,972
1908		466	102	425	200	1,119	156	2,108		2,312						6,888
1909	1	458	107	253	209	1,048	135	2,110		2,309						6,630
1910	1	457	109	212	188	1,091	128	2,663		2,585						7,434
1911	1	453	109	206	181	1,083	229	2,718		2,807						7,787
1912	1	447	106	159	116	999	107	3,106	2	2,793						7,836
1913		437	100	172	119	897	105	3,601		2,785						8,216
1914		424	97	196	119	975	100	3,694		2,920						8,525

REFRIGERATOR CARS

1905		51	90	3,720	5,517	15,809	1,014		643							26,844
1906	1	33	92	3,318	6,197	19,315	1,188		1,638							31,782
1907	1	30	44	2,915	6,839	19,861	1,233		2,694							33,617
1908	1	23	42	2,178	6,372	15,373	1,224		2,717							27,930
1909	1	14	37	2,007	6,693	15,509	1,215	4	2,724							28,204
1910	1	14	10	1,585	6,800	18,652	1,063	33	2,730	30						30,918
1911	1	9	24	1,382	5,740	19,746	1,734	340	2,760	50						31,786
1912		4	39	895	5,438	18,126	1,971	1,325	2,845	50						30,693
1913		8	32	2,086	6,086	24,468	3,653	3,342	3,664	50						43,389
1914		6	20	1,956	5,630	26,132	4,293	4,988	5,811	50						48,886

(Continued on next page)

III. Classification of Cars as to Capacity (Maximum Load in Pounds) — *Continued*

Year	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000	110,000	120,000	30,000	40,000 to 150,000	180,000 to 200,000 and Over	Total
OTHER CARS																
1905	1,283	1,736	1,286	8,851	8,136	11,840	1,709	9,397	600	6,835		12			[280,000]	51,685
1906	1,319	1,823	1,445	8,551	8,962	9,238	2,641	10,941		10,489	163	12				55,584
1907	2,242	1,897	1,235	7,282	8,507	12,057	2,704	14,388	21	17,572	163	12			1	68,081
1908	1,886	1,382	1,049	7,809	6,835	11,042	2,716	18,559	47	18,479	250				1	70,055
1909	804	1,461	1,344	7,918	6,154	11,388	2,760	22,245	96	20,139	246				1	74,556
1910	828	1,224	1,524	6,641	4,959	11,916	2,696	24,652	97	23,625	248				1	78,411
1911	610	1,398	1,558	6,108	3,542	10,814	2,348	26,689	90	27,598		100			1	80,856
1912	376	1,131	1,441	5,943	4,043	11,293	3,675	28,138	90	33,216	501	366	5		1	90,219
1913	128	947	720	3,589	3,380	10,240	3,624	28,718	90	39,351	501	615	7		1	91,911
1914	347	956	537	3,196	2,511	10,034	3,612	29,160	90	43,148	1,745	665	12		4	96,017
TOTAL FREIGHT EQUIPMENT																
1905	4,047	9,528	27,309	284,616	206,950	738,704	26,261	294,462	2,308	132,729	444	56		6	200	1,727,620
1906	3,734	8,026	19,603	244,135	195,944	768,647	30,169	362,336	4,175	195,911	675	70		9	201	1,833,635
1907	4,277	7,244	10,132	204,583	178,827	802,187	34,652	452,070	5,054	285,241	1,476	60		12	202	1,986,017
1908	3,539	6,559	6,697	150,499	173,718	832,669	39,838	513,251	6,217	360,158	2,817	54	5	11	202	2,096,234
1909	2,421	5,785	5,865	126,500	150,009	830,612	38,926	522,446	7,891	376,988	3,824	54		15	2	2,071,338
1910	1,894	5,254	4,896	106,741	125,228	826,185	39,310	634,676	6,346	370,001	12,929	54	9	4	4	2,133,581
1911	1,643	5,170	4,548	87,920	105,666	823,856	39,663	614,788	6,688	475,871	29,059	155	286	14	1	2,195,331
1912	1,156	4,631	5,651	73,216	95,182	802,622	39,369	642,734	6,770	509,624	33,523	429	303	18	11	2,215,239
1913	645	3,826	4,200	58,074	83,454	766,136	43,408	691,078	7,572	568,823	44,544	670	315	533	11	2,273,289
1914	608	3,548	3,506	48,762	70,526	720,095	42,957	726,777	9,709	637,741	56,006	716	320	3,612	764	2,325,647

IV. Percentage of Freight Cars according to Capacity

Year	10,000 to 20,000	30,000 to 40,000	50,000 to 60,000	70,000 to 80,000	90,000 to 100,000	110,000	120,000 to 200,000
			BOX CARS				
1905	0.4	19.3	66.0	12.0	2.2		
1910	0.1	5.5	60.8	27.5	6.1		
1913	0.09	2.8	54.41	35.3	7.4		
1914	0.08	2.2	51.2	37.82	8.7		
			FLAT CARS				
1905	2.4	30.6	43.0	20.5	3.5		
1910	1.3	13.8	42.8	32.4	9.7		
1913	0.9	9.3	38.0	37.4	14.4		
1914	0.8	8.0	35.9	38.9	16.3		0.1
			STOCK CARS				
1905	0.3	27.2	70.4	1.5	0.6		
1910	0.2	14.9	69.7	12.3	2.9		
1913	0.1	10.9	68.2	16.8	4.0		
1914	0.1	9.6	65.4	22.0	2.9		
			COAL CARS				
1905	0.4	12.9	42.1	28.3	16.2	0.07	0.03
1910	0.1	1.9	24.4	39.0	33.1	1.5	
1913	0.06	0.5	15.3	29.7	49.3	5.05	0.09
1914	0.03	0.4	11.6	28.3	53.17	6.0	0.5
			TANK CARS				
1905	9.8	5.5	23.8	30.7	30.2		
1910	6.2	4.3	17.2	37.5	34.8		
1913	5.3	3.3	12.4	45.1	33.9		
1914	5.0	3.4	12.8	44.5	34.3		
			REFRIGERATOR CARS				
1905	0.2	14.2	79.4	3.8	2.4		
1910	0.05	5.15	82.3	3.5	9.0		
1913		4.9	70.4	16.1	8.6		
1914		4.0	65.0	19.0	12.0		
			OTHER CARS				
1905	5.8	19.7	38.6	21.5	14.4		
1910	2.6	9.1	22.9	34.9	30.2	0.3	
1913	1.2	4.7	14.8	35.2	42.9	0.5	0.7
1914	1.4	3.9	13.1	34.1	45.0	1.8	0.7
			TOTAL FREIGHT EQUIPMENT				
1905	0.8	18.1	54.7	18.57	7.8	0.02	0.01
1910	0.3	5.2	44.6	31.6	17.6	0.7	
1913	0.2	2.73	37.4	32.3	25.4	1.9	0.07
1914	0.2	2.3	34.0	33.2	27.7	2.4	0.2

V. Freight Equipment owned in 1914 by Railroad Companies owning more than 500 Locomotives

EASTERN DISTRICT

Roads	Box		Flat		Stock		Coal		Tank		Refrigerator		Other		Total	
	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity
Pennsylvania R. R.	46,809	2,074,565	2,098	103,935	695	23,800	97,146	4,763,928	495	6,629	5,825	248,755			153,068	7,221,612
N. Y. Cen'l.	40,887	1,499,935	5,082	191,930	555	15,555	24,953	1,093,088			5,546	175,995			77,023	2,976,503
Balt. & Ohio	30,509	1,029,900	1,527	66,610	837	25,110	53,591	2,505,705	10	200	1,292	41,670	6	356	87,772	3,669,550
N. Y., N. H. & H.	25,113	772,300	1,752	65,383			8,603	327,680			249	7,470			35,717	1,172,833
Pennsylvania Co.	20,075	850,840	1,653	72,605	1,108	51,200	36,498	1,782,965			1,074	33,750			60,408	2,791,360
L. S. & M. S.	22,721	863,935	2,949	87,320	879	22,512	26,530	1,242,545			3,881	126,105			56,960	2,342,417
Erie	28,782	1,040,955	1,446	64,460	79	2,335	21,269	968,830			1,524	44,855			53,100	2,121,435
Boston & Maine	13,443	411,665	1,470	43,630	128	3,290	8,274	265,650			343	9,990	306	8,850	23,964	743,075
Phila. & Reading	8,500	284,958	253	12,090	54	1,620	24,060	917,745	34	1,360	484	15,560	7,345	329,842	40,730	1,563,175
P. C. C. & St. L.	7,069	306,300	871	36,515	1,432	67,510	20,388	1,029,965			617	25,425	72	2,160	30,377	1,465,715
D. L. & W.	15,287	458,610	110	3,300	195	5,850	10,817	432,050	17	680	980	29,400			27,478	932,050
Lehigh Valley	20,474	686,815	166	5,400	362	7,360	18,714	782,698			1,320	33,255	4,885	201,233	45,921	1,716,761
C. C. C. & St. L.	13,755	457,575	1,462	52,755	763	23,200	9,474	414,130							25,454	947,660
Michigan Central	16,942	608,300	2,541	74,820	758	21,690	4,531	206,610	22	450	514	12,690			25,308	924,560
Wabash	12,475	414,350	758	27,780	1,129	43,830	7,002	322,630			71	1,420	274	9,070	21,709	819,080
Central of N. J.	7,697	231,415	156	6,240	50	1,500	10,623	449,590			482	14,080	4,792	212,185	23,800	915,010
Total	330,538	11,992,418	24,294	914,773	9,024	316,362	382,473	17,505,809	578	9,319	24,202	820,420	17,680	763,696	788,789	32,322,796

SOUTHERN DISTRICT

Roads	Box No.	Box Capacity	Flat No.	Flat Capacity	Stock No.	Stock Capacity	Coal No.	Coal Capacity	Tank No.	Tank Capacity	Refrigerator No.	Refrigerator Capacity	Other No.	Other Capacity	Total No.	Total Capacity
Southern	26,816	824,225	1,711	71,730	836	25,080	17,564	818,050			239	9,130	84	2,585	47,250	1,750,800
Illinois Central	28,227	1,088,260	3,050	130,745	2,136	59,080	26,285	1,187,640	10	400	729	21,870			60,437	2,487,995
L. & N.	18,248	618,342	3,298	128,895	1,473	48,190	19,799	833,095			1,371	38,430	1,937	89,147	46,126	1,776,099
N. & W.	8,346	299,245	773	32,445	2,595	97,735	35,769	1,878,965							47,483	2,308,390
A. C. L.	21,855	639,080	5,765	176,180	74	2,055	635	25,400			5	125	1,205	29,570	29,539	872,410
C. & O.	8,386	272,290	1,236	49,015	832	23,840	33,542	1,645,775			9	270	50	2,000	44,055	1,993,190
S. A. L.	10,254	326,820	2,816	83,990	71	2,130	4,078	166,600					410	20,400	17,629	599,940
Total	122,132	4,068,262	18,649	673,000	8,017	258,110	137,672	6,575,525	10	400	2,353	69,825	3,686	143,702	292,519	11,788,824

Figures of Capacity are given in Tons of 2000 pounds each.

V. FREIGHT EQUIPMENT OWNED IN 1914 BY RAILROAD COMPANIES OWNING MORE THAN 500 LOCOMOTIVES — *Continued*

WESTERN DISTRICT

Roads	Box		Flat		Stock		Coal		Tank		Refrigerator		Other		Total	
	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity
A. T. & S. F	31,937	1,099,005	2,870	99,175	3,147	84,150	9,422	337,255	2,371	92,979			4,844	183,480	54,591	1,896,044
C. B. & Q.	30,958	1,193,935	1,572	70,585	7,534	196,815	21,800	1,056,090	213	9,520	2,997	97,190	83	1,603	65,157	2,625,738
So. Pac.	18,199	797,570	6,106	256,490	2,542	83,250	2,602	126,125	2,207	98,540	160	4,800			31,816	1,366,775
C. M. & St. P.	44,161	1,486,953	4,726	145,788	5,797	170,840	4,924	220,955			2,325	75,340	3,848	179,790	65,781	2,279,666
C. & N. W.	33,149	1,160,755	4,989	201,084	4,569	129,330	14,021	600,165			2,443	72,405	5,922	240,341	65,093	2,404,080
Grt. Northern	33,590	1,183,994	4,595	167,274	1,842	43,262	2,161	96,030			2,833	84,090	10,257	487,975	55,278	2,062,625
No. Pac.	26,358	994,930	8,654	305,195	2,702	65,285	5,336	255,990	62	2,555	4,080	130,320	1,782	69,955	48,974	1,824,230
C R. I. & P	28,978	1,040,445	1,944	82,440	4,557	153,265	7,186	308,780			2,005	60,045			44,670	1,644,975
Un. Pac.	12,100	527,080	768	38,360	2,984	102,110	2,349	104,840			9	255	1,858	92,900	20,068	865,545
St. L. & S. F.	16,610	566,240	1,107	43,305	2,100	72,510	11,281	512,690	495	24,750	2	60	646	25,280	32,241	1,244,835
St. L. I. M. & S.	11,506	398,105	1,723	56,495	1,359	49,530	5,493	232,560							20,081	736,690
M. K. & T.	17,209	502,705	937	31,360	972	28,020	5,368	209,605	2	60	383	11,250	644	19,320	25,515	802,320
M. St. P. & S. Ste. M.	20,054	609,610	2,225	68,890	824	24,375	566	11,820			424	11,685	2,534	104,720	26,627	831,100
Mo. Pac.	13,825	435,470	595	17,335	1,175	35,240	7,368	276,850							22,963	764,895
D. & R. G.	6,264	202,500	820	29,720	1,852	59,795	7,488	299,815			304	7,960	1,208	48,470	17,936	648,260
Total	344,898	12,199,297	43,621	1,613,496	43,956	1,297,777	107,365	4,649,570	5,350	228,404	17,965	555,400	33,626	1,453,834	596,791	21,997,778

(Continued on next page)

V. Freight Equipment owned in 1914 by Railroad Companies owning more than 500 Locomotives — *Continued*

UNITED STATES

Road	Box		Flat		Stock		Coal		Tank		Refrigerator		Other		Total	
	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity	No.	Capacity
	1,043,796	36,622,074	146,133	5,214,949	82,971	2,597,278	899,314	40,583,490	8,530	340,722	48,886	1,577,973	96,017	4,040,612	2,325,647	90,977,098

Proportion of Equipment to that of United States (per cent)

Road	Box No.	Box Capacity	Flat No.	Flat Capacity	Stock No.	Stock Capacity	Coal No.	Coal Capacity	Tank No.	Tank Capacity	Refrigerator No.	Refrigerator Capacity	Other No.	Other Capacity	Total No.	Total Capacity
EASTERN DISTRICT																
16 Roads	31.7	35.5	16.6	17.5	10.9	12.2	42.5	43.1	6.8	2.5	49.5	52.0	18.4	18.9	33.9	35.5
SOUTHERN DISTRICT																
7 Roads	11.7	11.1	12.8	12.9	9.7	9.1	15.3	16.2			4.8	4.4	3.8	3.5	12.6	13.2
WESTERN DISTRICT																
15 Roads	33.0	33.3	30.0	30.9	53.0	50.0	12.0	11.4	62.7	67.0	36.6	35.2	35.0	36.0	25.6	24.2
ENTIRE THREE DISTRICTS																
38 Roads	76.4	79.9	59.4	61.3	73.6	71.3	69.8	70.7	69.5	69.5	90.9	91.6	57.2	58.4	72.1	72.9

VI. Classification of Passenger Equipment owned by Railroad Companies

Year	First Class Coaches	Second Class Coaches	Combination Cars	Emigrant Cars	Dining Cars	Parlor Cars	Sleeping Cars	Baggage Mail & Express	Other Cars	Total
1900	16,738	3,358	4,399	225	353	499	393	7,964	784	34,713
1905	19,024	3,682	5,335	172	659	638	470	9,450	1,283	40,713
1906	19,364	4,128	5,432	186	711	703	489	9,892	1,357	42,262
1907	19,948	4,266	5,569	177	803	656	541	10,379	1,634	43,973
1908	19,956	4,816	5,509	166	832	659	500	10,864	1,990	45,292
1909	20,147	5,094	5,581	138	844	684	420	10,997	1,679	45,584
1910	20,518	5,363	5,697	97	950	634	490	11,524	1,822	47,095
1911	20,469	5,144	4,873	78	1,054	687	655	11,959	1,986	46,905
1912	22,418	5,543	5,806	89	1,133	699	673	12,766	2,363	51,490
1913	22,586	5,489	5,502	95	1,209	547	637	12,943	2,692	51,700
1914	23,496	5,213	5,639	84	1,282	561	636	13,607	2,948	53,466

INCREASE

Year	First Class Coaches	Second Class Coaches	Combination Cars	Emigrant Cars	Dining Cars	Parlor Cars	Sleeping Cars	Baggage Mail & Express	Other Cars	Total
1900 to 1905	2,286	324	936	Dec. 53	306	139	77	1,486	499	6,000
1910	1,494	1,681	362	75	291	Dec. 4	20	2,074	539	6,382
1913	2,068	126	Dec. 195	2	259	" 87	147	1,419	870	4,605
1914	910	Dec. 276	Inc. 137	11	73	Inc. 14	Dec. 1	664	256	1,766
1905 to 1914	4,472	1,531	304	Dec. 88	623	77	166	4,157	1,665	12,753
Per annum	497	170	34	—	69	—	18	462	185	1,417

VII. Passenger Equipment in 1914, owned by Railroad Companies owning more than 500 Locomotives

EASTERN DISTRICT

Roads	First Class	Second Class	Combination	Emigrant	Dining Cars	Parlor Cars	Sleeping Cars	Baggage Express and Postal	Other Cars	Total
Pennsylvania	1,529	80	289		79			775	68	2,820
New York Central	858	623	211	20	48			612	369	2,741
Baltimore & Ohio	599	38	133	30	53			416	4	1,273
N. Y., N. H. & H.	1,508		247		20			318	267	2,360
Pennsylvania Co.	210	231	58		53			237	8	797
L. S. & M. S.	170	172	28		21			343	93	827
Erie	629		119	1	17	15		347	71	1,199
Boston & Me.	1,185	10	248		12	9		380	159	2,003
Phila. & Reading	298	324	157		6			135	1	921
P. C. C. & St. L.	274	23	59					193		549
D. L. & W.	422	41	89		11			294	8	865
Lehigh Valley	244	21	49		10			137	133	594
C. C. C. & St. L.	267	41	67		15	8		182		580
Mich. Central	169	65	37		21			179	32	503
Wabash	119	27	66		17	7		117	66	419
Central of N. J.	491		104		2			99		696
Total	8,972	1,696	1,961	51	385	39		4,764	1,279	19,147

SOUTHERN DISTRICT

Roads	First Class	Second Class	Combination	Emigrant	Dining Cars	Parlor Cars	Sleeping Cars	Baggage Express and Postal	Other Cars	Total
Southern	495	73	129		31	8		356	2	1,094
Illinois Central	505	127	50		32	15	5	307	151	1,192
L. & N.	396		65		13	6		173		653
N. & W.	257		31		10			145	1	444
A. C. L.	230	120	130		8			177		665
C. & O.	159	36	52	7	11	21		99		385
S. A. L.	120	36	100		18	2		89		365
Total	2,162	392	557	7	123	52	5	1,346	154	4,798

WESTERN DISTRICT										
. T. & S. F.	641	155	140		33	9		542	8	1,528
. B. & Q.	644		253		41	14		269	41	1,262
o. Pac.	988	8	127		94			659	10	1,786
. M. & St. P.	507	170	12		47	28	217	589		1,570
. & N. W.	1,003	9	173		34	65		385	241	1,910
reat Northern	386		43		45	28	189	470	3	1,164
o. Pac.	192	184	68		58	15	130	267	235	1,149
. R. I. & P.	263	330	98		46	4		359	42	1,142
n. Pac.	217		44		49	2		216	34	562
. L. & S. F.	209	135	80		32			194	32	682
. L. I. M. & S.	68	59	47		5			46		225
. K. & T.	168	116	80		10			124	13	511
. St. P. & S. S. M.	128	52	26	16	19	19	42	109	11	422
lo. Pac.	173	84	69		15			129		470
. & R. G.	132	62	25		15	5		115	17	371
Total	5,719	1,364	1,285	16	543	189	578	4,373	687	14,754
nited States	23,496	5,213	5,639	84	1,282	561	636	13,607	2,948	53,466
PROPORTION OF EQUIPMENT TO THAT OF UNITED STATES (PER CENT.)										
EASTERN DISTRICT										
6 Roads	38.2	32.5	34.8	60.7	30.0	7.0		35.0	43.4	37.7
SOUTHERN DISTRICT										
Roads	9.0	7.5	9.9	8.3	9.6	9.3		9.9	5.2	9.0
WESTERN DISTRICT										
5 Roads	24.3	26.1	22.8	19.0	42.4	33.7	90.9	32.1	23.2	27.6
ENTIRE THREE DISTRICTS										
8 Roads	71.5	66.1	67.5	88.0	82.0	50.0	90.9	77.0	71.8	74.3

VIII. All-steel Passenger-train Equipment in the United States

Year	Road	Character	No. of Cars
1904	Erie	Baggage car	1
		Postal car	1
1906	N. Y., N. H. & H.	Postal car	2
	Pennsylvania	Baggage car	1
		Day car	1
1907	So. Pacific	Day car	1
	Union Pacific	Day car	1
		Postal car	1
	Pullman Co.	Sleeping car	1
	Pennsylvania	Day car	1
		Postal car	5
1908	Pennsylvania	Day car	155
		Baggage car	22
		Postal car	14
		Dining car	10
		Combination baggage-cars	5
1908–09	So. Pacific	Day cars	360
		Baggage cars	180
		Arm-chair cars	70
		Postal cars	45
		Post-office cars	9
	Pullman Co.	Sleeping cars	487
	Pennsylvania	Day cars	236
		Postal cars	123
		Dining cars	44
		Baggage cars	16
		Postal and Baggage cars	11
1909	Western Pacific	Day cars	51
1910	St. Louis & San Francisco	Baggage cars	31
	Harriman Lines	Day cars	434
		Baggage cars	1
	Western Pacific	Day cars	120
	El Paso	Day cars	19
	Chi., R. I. & Pacific	Day cars	40
	N. Y. C. & H. R.	Baggage cars	35
		Postal cars	20
	Baltimore & Ohio	Day cars	72
	Lehigh Valley	Day cars	46
	Chicago, Mil. & St. P.	Day cars	45
	Pennsylvania	All kinds	400
	Total		3117

Compiled from article on "Construction of Iron Passenger Cars in the United States of America," by F. Gutbrod. Bulletin International Railway Congress, November, 1912.

IX. Car Construction in the United States, 1909 and 1914

	1909		1914		Increase Per Cent.	
Establishments	280		242		Dec. 13.6	
Cars Built	No.	Value	No.	Value	No.	Value
Steam						
Freight	96,652	$79,763,326	131,799	$110,002,456	36.4	37.9
Passenger	1,819	15,120,961	3,558	45,027,083	95.6	197.8
Total	98,471	94,884,287	135,357	155,029,539	37.5	63.4
Electric	2,772	7,263,109	2,821	10,041,888	1.8	38.3
Total	101,243	$102,147,396	138,178	$165,071,427	36.5	61.6

X. Defective Safety Appliances, 1910 to 1914

Compiled from Report of Division of Safety, Interstate Commerce Commission, for 1914, including only inspections of freight-equipment of 10,000 cars or more.

	1910		1911		1912		1913		1914	
Roads	No. of Cars Inspected	Defects Per Cent.	No. of Cars Inspected	Defects Per Cent.	No. of Cars Inspected	Defects Per Cent.	No. of Cars Inspected	Defects Per Cent.	No. of Cars Inspected	Defects Per Cent.
1	1,941	9.4	2,585	6.6	3,514	8.8	6,528	8.3	11,043	7.1
2	2,526	3.0	5,806	2.0	6,985	3.1	8,845	3.4	11,541	4.0
3	4,035	3.8	4,794	2.9	11,274	4.9	15,307	4.3	15,248	3.6
4	4,083	2.9	6,641	3.5	7,377	5.8	14,307	9.6	20,813	6.2
5	4,142	6.1	3,704	3.4	5,362	7.3	11,463	8.3	10,961	7.7
6	5,488	3.9	9,188	3.3	6,481	4.6	12,431	4.6	15,223	3.2
7	5,844	6.7	5,438	5.5	6,948	7.3	9,842	6.3	12,784	6.6
8	6,912	12.4	12,183	7.7	3,763	14.6	10,562	12.3	11,570	11.9
9	7,184	5.6	10,897	5.0	7,177	6.8	11,789	6.0	10,555	5.7
10	7,461	3.2	8,793	5.3	12,320	5.0	22,758	11.1	24,510	8.5
11	7,796	6.8	8,434	7.8	14,753	9.1	24,589	10.7	28,581	7.7
12	8,034	6.2	9,165	5.6	5,322	4.0	10,719	10.8	11,695	6.1
13	8,746	2.3	7,790	1.3	7,458	2.1	12,002	2.5	13,684	2.4
14	9,006	5.6	14,450	4.7	8,998	8.6	20,775	10.7	20,781	7.5
15	10,266	8.3	11,816	5.9	11,981	8.1	20,410	7.2	19,066	5.5
16	10,360	2.6	10,562	2.7	12,550	3.6	17,889	3.8	23,316	3.2
17	10,829	6.5	12,118	6.6	11,896	5.4	14,549	9.4	15,925	5.9
18	10,830	8.4	13,276	8.4	8,255	14.6	21,037	14.5	18,387	9.9
19	11,435	6.5	11,755	6.5	8,444	8.4	17,783	8.3	17,195	8.9
20	11,661	3.9	9,167	4.3	10,435	5.8	16,568	4.9	14,278	4.2
21	11,746	3.8	10,064	2.7	10,975	5.6	13,348	4.3	11,088	1.9
22	11,984	2.5	10,707	1.6	14,481	7.1	14,732	2.8	15,975	1.1
23	12,121	5.4	14,693	4.6	11,842	7.4	22,466	7.9	21,497	7.6
24	13,152	3.0	13,790	3.3	12,365	3.6	18,526	5.3	21,358	5.4
25	13,281	2.0	21,149	1.5	12,379	2.0	25,345	2.0	27,796	1.7
26	20,672	2.3	14,984	2.1	17,318	4.6	24,633	3.9	25,121	2.4
27	25,692	4.5	21,405	4.3	23,488	5.8	31,581	4.9	27,416	4.2

XI. Passenger Equipment Acquired, 1909–1916

Year	Total	Per Cent.		
		Per Cent. All-steel	Steel Under-frame	Wooden
1909	1,880	26.0	22.6	51.4
1910	3,638	55.4	14.8	29.8
1911	3,756	59.0	20.3	20.7
1912	2,660	68.7	20.9[2]	10.4
1913	3,350	63.0	30.4[2]	6.6
1914	4,495	74.6	29.9[2]	4.5
1915	1,696	73.7	20.1[2]	6.2
1916	1,445	92.5	7.3[2]	0.2
1917[1]	1,759	82.5	16.9	0.6
	24,679			

Now in service, 36,169 wooden cars. Cost of replacement, $881,287,000. Steel passenger-train equipment in service, cost, $325,000,000. Act of Congress, August 24, 1912, all full postal cars after July 1, 1917, must be all-steel or with steel under-frames.

Passenger Train Equipment, December 31, 1916

Region	No. Lines	In Service			Under Contract		
		All-steel	Steel Under-frame	Wooden	All-steel	Steel Under-frame	Wooden
New England	13	643	344	4,056	49	3	—
Eastern . .	87	6,223	1,881	12,806	886	64	2
So. Eastern .	63	548	603	4,212	235	2	3
No. Western .	29	734	212	3,640	16	—	—
Southern . .	49	678	452	2,876	40	—	—
Western . .	52	3,652	1,491	8,922	103	42	5
Pullman Co. .	1	3,276	1,403	2,617	122	187	—
Total . .	294	15,754	6,386	39,169	1,451	298	10
United States		61,309			1,759		
Canada . .	8	108	385		51		

[1] Under construction, Jan. 1st. [2] Includes wooden cars rebuilt.

CLASSES OF EQUIPMENT

Postal	904	194	237	51	1	—
Mail and baggage	851	454	2,251	117	4	3
Mail, bagg., and exp.	46	57	547	5	2	1
Bagg. and pass'r	691	204	3,129	103	—	—
Bagg. or exp.	2,029	1,485	6,608	324	60	6
Passenger	6,047	1,906	20,906	658	42	—
Sleepers and diners	4,095	1,829	4,432	182	188	—
Business	42	152	736	10	1	—
Motor	1,044	105	323	1	—	—
Total	15,754	6,386	39,169	1,451	298	10

Bulletin No. 93. Special Committee on Relations of Railway Operations to Legislation. From Railway Age Gazette, June 29, 1917.

APPENDIX IV

ALTITUDES, TUNNELS, BRIDGES

NOTES AND TABLES I TO IX

I. HIGHEST RAILWAY ALTITUDES

Compiled from Railway Age Gazette, July 8, 1910, and other sources.

AMERICA

COUNTRY	LOCATION	ALTITUDE FT.	LINE
Bolivia	Collahuasi	15,809	Antofagasta & Bolivia Ry.
Peru	Galera Tunnel	15,588	Peruvian Central Ry.
	Portez del Cruzera	14,665	Peruvian Southern Ry.
United States	Corona	11,660	Denver & Salt Lake R. R.
	Fremont Pass	11,330	Rio Grande Southern R. R.
	Marshall Pass	10,856	Denver & Rio Grande R. R.
Chile	La Cumbre	10,456	Transandine Ry.
United States	Cumbres	10,315	Denver & Rio Grande R. R.
	Lizard Head	10,248	Rio Grande Southern R. R.
	Tennessee Pass	10,232	Denver & Rio Grande R. R.
	Laveta Pass	9,393	Denver & Rio Grande R. R.
Mexico	Nanacamilpa	8,990	Interoceanic Ry.
United States	Sherman	8,240	Union Pacific R. R.
	Cerro Summit	7,968	Denver & Rio Grande R. R.
Mexico	Las Vegas Summit	7,923	Interoceanic Ry.
United States	Bozeman Tunnel	5,560	Northern Pacific Ry.
	Mullan Tunnel	5,560	" " "
Canada	Stephen	5,296	Canadian Pacific Ry.
Venezuela	Caracas	3,135	La Guaira — Caracas
United States	Gallitzin	2,154	Pennsylvania R. R.

EUROPE

COUNTRY	LOCATION	ALTITUDE FT.	LINE
Switzerland	Jungfraujoch	11,220	Jungfrau Ry.
	Eismeer	10,368	" "
	Bernina Pass	7,382	San Moritz — Poschiavo
	Albula Tunnel	6,133	Thusio — San Moritz
Austria	Brenner Pass	4,485	Verona — Innsbrück
France	Mont Cenis	4,248	Paris — Turin
Austria	Arlberg Tunnel	4,100	Rhine Valley — Innsbrück
Switzerland	Loetschberg Summit	4,077	Spiess — Brieg
Austria	. . . .	4,018	Trieste — Salzburg
	Toblach	3,937	Southern Tyrol
Switzerland	St. Gotthard Tunnel	3,789	Lucerne — Lugano
	Convers	3,445	Neuchâtel — Locle
Russia	. . . .	3,182	Transcaucasus Ry. (Poti—Tiflis)
Austria	Semmering	2,940	Vienna — Bruck
Switzerland	Simplon	2,313	Brieg — Iselle
	Ricken Tunnel	2,041	Toggenburg — Lake of Zürich
Italy	Pracchia	2,000	Bologna — Florence

AFRICA

Uganda . . .	Mati Summit . . .	8,320	Uganda Ry.
	Kikuyu Summit . .	7,857	" "

II. Tunnels in Europe not Less than One Mile in Length

Country	Name of Tunnel	Length Miles	Single or Double Track	Constructed	Line
Austria . .	Arlberg . . .	6.36	Double T.	1880–85	
	Tauern . . .	5.29	" "	1901–08	
	Karawanken .	4.91	" "	1902–06	
	Wocheiner . .	3.90	" "	1901–05	
	Bosruck . . .	2.96	Single T.	1902–06	
	Gt. Hartberg .	1.53	" "		
France . .	Mont Cenis . .	7.98	Double T.	1857–71	
	Somport . . .	4.86	Single T.		
	Mont d'Or . .	3.75	Double T.	–1915	Paris — Lausanne
	Puymorens . .	3.18	Single T.		
	Echarmeaux .	2.58	Double T.	1892–95	
	Vizzavona . .	2.44	Single N. G.	1880–89	
	Col-de-Cabre .	2.34	Double T.	1885–90	
	Colle-St. Michel	2.16	Single N. G.	1898–01	
	Meudon . . .	2.07	Double T.	1887–00	
	Mont Lepine .	1.90	" "	1887–02	
	Caluire . . .	1.49	Single T.		
	Croix de l'Orme	1.29	Double T.		St. Etienne — St. Geo. d'Aurac
	Col-des-Montets	1.17	Single T.	1905–08	
Germany .	Cochern . . .	2.60	Double T.		
Gt. Britain	Severn . . .	4.12		1873–86	Gt. Western
	Totley	3.18			Midland
	Standedge . .	3.01	2 Single T. 1 Double T.		London & N. Western " " "
	Woodhead . .	3.00	Generally Double Track		Gt. Central
	Sudbury . . .	2.17			Gt. Western
	Disley	2.06			Midland
	Gildersome . .	2.06			London & N. Western
	Bramhope . .	2.04			North Eastern
	Festiniog . . .	2.03			London & N. Western
	Cowburn . . .	2.03			Midland
	Ponsbourne . .	1.52			Gt. Northern
	Sevenoaks . .	1.32			So. Eastern & Chatham
	Rhondda . . .	1.31			Rhondda & Swansea
	Morley . . .	1.30			London & N. Western
	Box	1.27			Gt. Western
	Catesby . . .	1.23			Gt. Central
	Dove Holes . .	1.23			Midland

II. TUNNELS IN EUROPE NOT LESS THAN ONE MILE IN LENGTH — *Continued*

COUNTRY	NAME OF TUNNEL	LENGTH MILES	SINGLE OR DOUBLE TRACK	CONSTRUCTED	LINE
Gt. Britain	Littleborough	1.21	Generally Double Track		Lancashire & Yorkshire
	Victoria (Liverpool)	1.19			London & N. Western
	Bolsover	1.16			Gt. Central
	Polehill	1.16			So. Eastern & Chatham
	Glenfarg	1.14			North British
	Queensbury	1.14			Gt. Northern
	Merthyr	1.13			Gt. Western
	Kilsby	1.12			London & N. Western
	Bleamoor	1.11			Midland
	Shepherd's Wall	1.11			So. Eastern & Chatham
	Strood	1.10			" " " "
	Oxted	1.09			Brighton & S. E. Joint
	Clayton	1.09			L., Brighton & So. Coast
	Sydenham	1.08			So. Eastern & Chatham
	Drewton	1.06			Hull & Barnsley
	Merstham, New	1.06			L., B. & So. Coast
	Wapping	1.06			London & N. Western
	Mersey	1.06			Mersey
	Greenock	1.06			Caledonian
	Bradway	1.05			Midland
	Sough	1.04			Lancashire & Yorkshire
	Watford, New	1.04			London & N. Western
	Abbott's Cliff	1.03			So. Eastern & Chatham
	Corby	1.03			Midland
	Wenvoe	1.02			Barry
	Sapperton	1.01			Gt. Western
	Sharnbrook	1.01			Midland
	Glaston	1.01			"
	Merstham, Old	1.01			So. Eastern & Chatham
	Midford	1.01			London & So. Western
	Belsize Second	1.01			Midland
	Watford, Old	1.01			London & N. Western
	Glenfield	1.00			Midland
	Clay Cross	1.00			"
	Harecastle	1.00			No. Staffordshire
Italy	Ronco	5.16	Double T.–E.		Genoa — Milan
	Tende	5.03	" "[1]	1890–99	
	Turchino	4.00	" "	1889–94	
	Peloritana	3.38	Single T.		
	Cremolino	2.11	" "	1889–93	
	Gattico	2.05	" "		Borgomanero — Arona
	Giovi	2.02	Double T.		Genoa — Milan
	Ariano	1.99	Single T.	1865–70	
	Varza	1.84	Double T.–E.		Simplon Route
	Pracchia	1.69	Single T.		Bologna — Pistoia
	Monte Falcione	1.61	" "		
	Starza	1.61	" "	1865–70	
	Laveno	1.42	Double T.	1880–82	
	Pitecchio	1.10	Single T.		
Russia	Suram	2.47	Double T.		Trans-Caucasus
Switzerland	Simplon	12.26	Single T.–E.	1898–06	
	St. Gotthard	9.14	Double T.	1872–82	
	Loetschberg	9.08	Double T.–E.	1907–13	Berne — Brieg
	Ricken	5.34	Single T.–E.	1904–08	
	Albula — N. G.	3.64	Single T.–E.	1898–03	Chur — St. Moritz

[1] E. = Electric Traction.

Supplementary Information from "Tunnels in Italy," Luigi Luigi

International Engineering Congress, San Francisco, Sept. 20–25, 1915

Name	Length Miles	Tracks	Constructed	
Italy				*New Lines*
Isoverde	12.08	D. T.	June '07–Mar. '11	Genoa — Milan
Montepiano . . .	11.58	D. T.	Oct. '09–Nov. '12	Florence — Bologna
Montorso	4.67	D. T.	Sept. '11–Apr. '15	Rome — Naples
Vivola	4.63	D. T.	Oct. '09–Nov. '12	" "
Massico	3.33	D. T.	Sept. '11–Apr. '15	" "
Borlasco	2.51	D. T.	Feb. '13–	Genoa — Arquata
Switzerland			*Opened*	*Between*
Grenchenberg . . .	5.30	S. T.	Oct. 1, '15	Münster — Grenchen
Hauenstein — Base .	5.05	D. T.	Jan. '16	Tecknau — Olten
Eigerwand I. . . .	3.06	S. T.[1]	June 18, '03	Jungfrau Ry.
Weissenstein . . .	2.30	S. T.[1]	Aug. 1, '08	Oberdorf — Gänsbrunnen
Wasserfluh	2.21	S. T.[1]	Oct. 3, '10	Bodensee — Toggenburg
Albis	2.08	S. T.[1]	June 1, '97	Sihlbrugg — Baar
Des Loges	2.02	S. T.[1]	July 15, '60	Les Hauts — Convers
De La Croix . . .	1.84	S. T.[1]	Mar. 30, '77	St. Ursanne — Courgenay
Bötzberg	1.57	D. T.	Aug. 2, '75	Schinznach — Effingen
Hauenstein	1.55	D. T.	May 1, '58	Laufelfingen — Olten
Jaman	1.50	S. T.[1]	Oct. 1, '03	Oberland-Bernois Ry.
Tasna	1.46	S. T.[1]	July 15, '13	Rhaetian Ry.
Eigerwand II. . . .	1.35	S. T.[1]	July 1, '12	Jungfrau Ry.
Musegg	1.30	S. T.[1]	June 1, '97	Lucerne — Meggen
Giovelier	1.24	S. T.[1]	Mar. 30, '77	Giovelier — St. Ursanne

III. Tunnels in America not Less than One Mile in Length

Country	Name of Tunnel	Length Miles	Single or Double Track	Constructed	Line
Canada . .	Connaught .	5.00	Double T.	1913–1916	Canadian Pacific
	Mount Royal	3.21	" " –E.[2]	–1914	Canadian Northern
	St. Clair . .	1.13	Single T.–V. E.	1889–1890	Grand Trunk
United States	Hoosac . .	4.70	E.	1855–1876	Boston & Maine
	Cascade . .	2.31	E.		Great Northern
	Snoqualmie .	2.25	Single T. E.	Jan., 1915	C., M. & St. Paul
	Stampede .	1.86	" " –V.		Northern Pacific
	Detroit River	1.50	Single T. Two tubes	1906–1909	
	Sandy Ridge	1.47	Single T.	–1914	Carolina, Clinchfield & Ohio
	East Boston	1.40			
	Big Bend .	1.23	Single T.–V.		Chesapeake & Ohio
	Otisville . .	1.00	Double T.		Erie Ry.

[1] Meter gauge.
[2] E. = Electric Traction. V. = Artificial Ventilation.

IV. Cost of Construction of Certain European Tunnels Over One Mile in Length

SINGLE-TRACK TUNNEL

Country	Name of Tunnel	Length Miles	Date of Construction	Cost per Lin. Yard	Notes
Austria	Bosruck	2.96	1902–06	$259	[1] Narrow gauge.
France	Vizzavona [1]	2.44	1880–89	300	[2] Including parallel driftway. Total cost, $15,000,000. Second tunnel commenced in 1912.
	Colle-St. Michel [1]	2.16	1898–01	147	
	Col-des-Montets	1.17	1905–08	432	
Italy	Cremolino	2.11	1889–93	212	
	Ariano	1.99	1865–70	308	
	Starza	1.61	1865–70	566	
Switzerland	Simplon [2]	12.26	1898–06	677 [3]	[3] Electric traction.
	Ricken	5.34	1904–08	244 [3]	
	Albula [1]	3.64	1898–03	212 [3]	

DOUBLE-TRACK TUNNELS

Country	Name of Tunnel	Length Miles	Date of Construction	Cost per Lin. Yard	Notes
Austria	Arlberg	6.36	1880–85	$823	
	Tauern	5.29	1901–08	621	
	Karawanken	4.91	1902–06	849	
	Wocheiner	3.90	1901–05	584	
France	Echarmeaux	2.58	1892–95	332	
	Col-de-Cabre	2.34	1885–90	319	
	Meudon	2.07	1887–00	531	
	Mont Lepine	1.90	1887–02	320	
Italy	Tende	5.03	1890–99	321	
	Turchino	4.00	1889–94	540	
	Laveno	1.42	1880–82	376	
Switzerland	St. Gotthard	9.14	1872–82	749	
	Loetschberg	9.03	1907–13	[3]	Estimated cost $10,000,000.

Supplementary Information from "Tunnels in Italy," Luigi Luigi

International Engineering Congress, San Francisco, September 20–25, 1915

Name of Tunnel	Length Miles	Date Constructed	Cost per Lin. Yard	Remarks
		Switzerland		
Weissenstein	2.30	–1908	$176.04	Single-track
Wasserfluh	2.21	–1910	138.30	" "
Tasna	1.46	–1913	119.58	" " Meter gauge

V. Artificially Ventilated Tunnels in the United States

Compiled by Charles S. Churchill, M. Inst. C. E., Assistant to the President, Norfolk & Western Railway

Road	Date of Installation	Gradient per Cent	End Situation of Fan	Length of Tunnel Feet	Section Square Feet	Contents Cubic Feet	Velocity of Air per Min. Feet	Air per Minute Cubic Feet	Time to Change Air Minutes	Remarks
Norfolk & Western Elkhorn	June, '01	+1.4 E.	West	3,000	S. T. 235	705,000	1,700	400,000	1.8	Train rating increased 100 tons
Chesapeake & O. Big Bend	Dec., '02	⅔ length +0.4 E.	East	6,500	" 250	1,625,000	1,400	350,000	4.6	
Pennsylvania Gallitzin	Apr., '05	+0.5 W.	East	3,600	" 324	1,166,400	1,550	502,000	2.3	
Pennsylvania Washington Terminal . . .	Dec., '07	+0.13 N.	North	4,050 760	" 265 6–2 tracks 260	3,371,800	1,230	640,000	3.3 for tubes	Two tubes, 530 sq. ft. Station end variable
Balt. & Ohio Kingwood	Dec., '10	+1.0 E.	West	4,138	S. T. 352	1,458,000	1,700	600,000	2.5	Train-rating increased 450 tons
Ches. & Ohio Lewis-Allegheny .	June, '11	+1.16 W.	East	4,026	" 318	1,280,200	1,600	508,800	2.5	
N. Y. Central Weehawken . . .	Sept., '11	+0.25 E.	West	4,365	D. T. 469	2,047,200	1,090	512,000	4.0	144 trains per day
Pennsylvania Baltimore	Sept., '11	+1.32 S.	South	4,963	" 432	2,150,000	1,154	500,000	4.3	193 trains per day
Chi. & Gt. West'n Winston	May, '11	+1.00 E.	West	2,500	S. T. 282	705,000	1,060	300,000	2.4	One fan 25 trains per day
Virginian Allegheny	Apr., '14	+1.22 E.	West	5,148	" 369	1,900,000	1,600	590,000	3.2	
No. Pacific Mullan	Oct., '14	+2.00 W.	East	3,899	" 283	1,103,000	1,940	550,000	2.0	
Norfolk & West'n Horse Shoe . . .	Aug., '14	+0.18 E.	East	3,291	" 300	1,000,000	1,800	540,000	1.8	
No. Pacific Stampede	Oct., '14	+0.74 E.	West	9,844	" 310	3,150,000	1,740	540,000	5.7	
Pennsylvania North and East Rivers	Sept., '10	+0.20 W		4,135 to 4,357	" 225			40,000 to 111,000		Tube tunnels 14 fans for emergencies

VI. London Underground Railways

METROPOLITAN AND DISTRICT RAILWAYS

Name, Locality and Progress	Miles	Total Cost	Cost per Mile	Opened	Remarks
Metropolitan . . .	72.5	$73,000,000	$941,393		
District	24.3	59,000,000	2,469,156		
Paddington to City .				Jan. 1863	
To Moorgate Street .				Dec. 1865	
Westminster . . .				" 1868	
Mansion House . .				July, 1871	
Aldgate.				Nov. 1876	
Circle completed .				Oct. 1884	
Electrified. . . .				1905	
Total	101.8	$132,000,000	$1,296,660		

TUBES

Name	Miles	Total Cost	Cost per Mile	Opened	Remarks
City and So. London .	7.3	$15,300,000	$3,234,042	1890	Commenced 1886
Central London . . .	6.9	19,200,000	2,095,892	1900	" 1898
Gt. Northern and City	3.4	10,200,000	2,782,608	1904	
Baker St. and Waterloo	4.7	15,200,000	3,000,000	1906	
Gt. N., Piccadilly and Brompton	9.4	32,800,000	3,489,361	1906	
Charing Cross, Euston and Hampstead . .	8.0	28,000,000	3,500,000	1907	
Total tubes . . .	39.7	$120,700,000	$3,042,570		
Metropolitan and District	101.8	132,000,000	1,296,660		
	141.5				
Waterloo and City . .	1.58				Merged with L. & S. W. Ry.
Total	143.08	$252,700,000			

VII. Underground Construction in and around New York City

MUNICIPAL SUBWAYS

Name	Miles of Line	Miles of Track	Cost	Remarks
Rapid Transit Subways . .	73			
Subways under construction	74			
Total	147			
Dual Subway System				
Interborough Rapid Transit		358		
Brooklyn Rapid Transit .		271		
Total		629		
Tracks in Manhattan . .		251		Including East River Bridges
" " Brooklyn . .		243		
" " the Bronx . .		100		
" " Queens . . .		35		
Total		629		
Estimated Cost — Old lines			$180,000,000	
New lines			327,000,000	
Total	147	629	507,000,000	

MUNICIPAL SUBWAY TUNNELS

Name and Location	Length	Diameter	Date	Remarks
New York Rapid Transit				
Harlem River. Two tubes	400 ft.	15 ft.	1904–05	
East River. Two tubes	4,150 ft.	15 ft.		
Headings met, N. Tube			Dec. 14, 1906	
Opened to traffic . . .			June 9, 1908	
Belmont Tunnel				
Forty-second St. to Long Island City . . .				Opening still delayed by litigation as to franchise
Commenced			July, 1905	
Partially completed .			Sept. 24, 1907	

UNDER CONSTRUCTION

Whitehall St. to Brooklyn	Commenced October, 1914
Old Slip to Brooklyn	
East Sixtieth St. to Long Island City	Authorized June 28, 1915

VII. Underground Construction in and around New York City
Continued

PENNSYLVANIA R. R. TUNNELS AND SUBWAYS

Name and Location	Length	Date	Remarks
River Tubes	6.8 miles, S. T.		
Land Tunnels	6.8 " "		
Total	13.6 miles, S. T.		
Total length of all tracks in Tunnels (exclusive of yard-tracks in station)	16.5 miles		
Bergen Portal, New Jersey, to Long Island Portal	5.3 "		
Harrison, N. J., to Jamaica, L. I.	11.92 "		
Continuous line, electrically operated			
West of Terminal Station	8.6 miles		
East " " "	12.0 "		
Total	20.6 miles		
Progress:			
Hudson River Tunnels, commenced		1904	
North tube connected		Sept. 12, 1906	
South " "		Oct. 9, 1906	
East River Tunnels, 4 parallel tubes	24,000 feet		Total length
Caisson to caisson	4,000 "		
Long Island Caisson to East Avenue Portal	2,000 "		
First tunnel pierced		Feb. 21, 1908	
Second " "		Mar. 4, 1908	
Thirty-third St. tunnel commenced		May, 1905	
" " " " pierced		Mar. 22, 1907	
Thirty-second St. tunnel commenced		May, 1905	
Thirty-second St. tunnel pierced		June 5, 1907	
First train through from Jersey City to Long Island		Nov. 18, 1909	
Terminal Station opened for Long Island traffic		Sept. 8, 1910	

Estimated Cost:	
New York Tunnels, including terminals	$100,000,000
Long Island R. R. electrification	35,000,000
Improvements in New Jersey	10,000,000
New York Connecting R. R.	14,000,000
Total	159,000,000

VII. Underground Construction in and around New York City
Continued

RAILROAD AND OTHER TUNNELS

HUDSON AND MANHATTAN R. R. ORGANIZED, 1901

Name and Location	Length	Date
Up-town tubes — Hoboken to Morton St. opened		Feb. 25, 1908
Down-town tubes — Jersey City to Cortlandt St. Opened		July 17, 1909
Extended from Cortlandt St. to 33d St.		Nov. 20, 1910
Jersey City and Hoboken tunnels, connected on New Jersey Shore		July 26, 1909
Extension to connect with tracks of Pennsylvania R. R. at Marion, N. J., and over that line to vicinity of Newark at Manhattan Transfer Station		Oct. 1, 1911
Extended thence by separate line to Newark, N. J.		Nov. 26, 1911
Total length of line with connection at Newark, N. J.	16 miles	

CONSOLIDATED GAS COMPANY

Name and Location	Length	
East River Tunnel		
Astoria to the Bronx	4,662 feet	
Section: 19 ft. 6 in. wide, 21 ft. in height		
150 ft. below river bed		
Cost: $5,000,000		

NEW YORK WATER-SUPPLY FROM ASHOKAN RESERVOIR

Name and Location	Length	Date
Tunnel from Yonkers under Manhattan Island and East River to Brooklyn	11 miles	
Diameter, 11 feet		
Headings under East River met		Apr. 30, 1913
750 ft. below water-level		
Deviation, after ten years of construction, less than half an inch		

VIII. Principal Bridges in New York City

EAST RIVER. — All bridges with clear headway of 135 feet at mean high water

Name and Description	Lengths and Weights	Widths, Decks and Roadways	Cost	Dates
Brooklyn. Suspension. 4 wire cables. Diameter of cables, 15¾ inches. Wires parallel. Towers, masonry, 276 ft. high. Saddles for chains 329 ft. above high water. Stiffening girders, 40 ft. deep, 67 ft. apart.	Total length, 5989 ft. With extensions, 7580 ft. Center span, 1595½ ft. Side spans, 930 ft. each. New York approach, 1562½ ft. Brooklyn approach, 971 ft.	Single deck, 80 ft. wide, carrying promenade; two roadways, each 16 ft. 9 in. wide; and two electric railway tracks. Width over all, 85 ft.	Cost of structure, $13,236,580. Real estate and land damages, $8,850,000. Total, $21,086,580.	Commenced, Jan. 3, 1870. Opened officially, May 24, 1883.
Williamsburg. Suspension. Four cables. Diameter of cables, 18¾ inches. Steel towers. Saddles, 332 ft. above high water.	Total length, with approaches, 7308 ft. Longest span, 1600 ft. Versed sine, 176 ft. Shore spans, 596 ft.	Two decks, carrying two elevated railroad tracks, four electric street railway tracks, two carriage-ways, two foot-ways and two bicycle paths. Width, 118 ft.	Cost of structure, $13,734,047. Land damages, $9,096,428. Total, $22,830,475.	Commenced, Nov., 1896. Opened, Dec., 1903.
Queensboro. Cantilever type, with suspended trusses, pin-connected. Height of towers above bottom chord, 185 ft. Height of trusses in longest span, 118 ft. Height of trusses at anchor piers, 48 ft. Height of trusses in center of channel span, 45 ft. Maximum grade on bridge, 3.4 per cent. Masonry in piers, 54,000 cu. yds. Maximum load, 16,000 lb. per lin. foot.	Total length, including approaches, 7449 ft. In addition, Queen's Plaza, 1152 ft. Channel span west of Blackwell's Island, 1182 ft. Span east of island, 984 ft. Island span, 630 ft. Longest sub-panel of trusses, 40 ft. Shortest sub-panel of trusses, 20¾ ft. Dead weight, including tracks and paving, 20,000 lb. per lin. ft. Weight of steel superstructure, 50,000 tons.	Width, 88 ft. Two decks. Upper deck, 67 ft. between railings, carrying four elevated railroad tracks and two sidewalks 11 ft. wide. Lower deck, 86 ft. between railings, carrying two street railway tracks outside, and two inside, of roadway 35 ft. wide. Center to center of trusses, 60 ft.	Cost of structure, $10,585,463. Land and damages, $745,511. Total cost, $11,339,974.	Commenced, July 19, 1901. Channel span connected, March 19, 1908. Opened, March 30, 1909.

Manhattan. Suspension. Diameter of cables, 21¼ inches. Foundations on rock, 100 ft. below mean high water, sunk in six months, with daily average of six inches, at cost of $1,000,000. Each anchorage contains 115,000 cu. yds. of granite and concrete.	Total length, 6856 ft. Main span between centers of towers, 1470 ft. Shore spans, each, 725 ft. from tower to anchorage. New York approach, 2067 ft. Brooklyn approach, 1869 ft.	Width to outside of railings, 122½ ft. Two decks. Upper deck carries four electric railroad tracks. Lower deck carries two electric railroad tracks on each side of a roadway 35 ft. wide, and two sidewalks on the outside, each 10 ft. wide.	Cost of structure, $10,421,431. Land and damages, $4,542,155. Total cost, $14,963,586.	Commenced, 1901. Opened officially, Dec. 31, 1909. Completed, July, 1910.
New York Connecting R. R. From Long Island to Port Morris, Bronx. Three bridges over channels with Long Island Sound, connected by viaducts.		60 ft. wide between trusses. 90 ft. over all. Suspended single deck, carrying four tracks.	Estimated cost, $20,000,000.	Central span connected, Oct. 1, 1915. Opened, April 2, 1917.
Hell Gate Bridge. Central span, arch steel truss, 220 ft. rise from hinges to crown of chords. Lower chord rectangular, 7½ ft. deep at crown and 10½ ft. at abutments.	Central span, 1017 ft. between abutments. Weight, 18,000 tons, 26 tons per lin. ft.			

HARLEM RIVER

Madison Avenue Bridge. Three spans; middle one drawbridge. Steel and concrete.	Drawbridge span, 300 ft.	Two roadways, each 27 ft. wide. Two sidewalks, each 9 ft. wide. Two street railway tracks.		Opened, July, 1910.
Hudson Memorial Bridge. Series of arches of reinforced concrete. Crown of central arch 85 ft. above water level. Concrete piers, 110 ft. wide, 30 ft. long, 180 ft. high, joined to bridge-approaches from abutments of central span.	Length, 1500 ft. Semi-circular arches of 108 ft. span. Four on Spuyten Duyvil side, and three on Manhattan side, with central span of 700 ft.	Separate decks for subway and street traffic, pipe-galleries and water-mains. Lower deck, 65 ft. wide. Upper deck overhangs lower deck, with 50 ft. roadway and two sidewalks.		
University Heights Bridge. Steel and masonry.	Total length, including approaches, 1000 feet. Swing-span, 265 ft. in length, operated by electricity.	Spans, 50 ft. wide. Roadway, 34 ft. wide. Sidewalks, 8 ft. wide.	Cost, including land for approaches, $1,000,000.	Opened, Jan. 8, 1908.

IX. Mauch Chunk Railroad

The Mauch Chunk Railroad was built in 1827 to transport coal by gravity from mines near Summit Hill a distance of nine miles to Mauch Chunk, where the coal was delivered to the Lehigh Canal. It superseded transport by wagons, each carrying four tons and drawn by two mules. The tonnage of 32,000 tons in 1827 had increased by 1859 to 450,000 tons. The trains consisted of fourteen cars of two tons capacity guided by a single man. Each train was accompanied by two stock cars carrying four mules each, who drew the empty trains back on the same track. The entire equipment was composed of 42 coal cars, 7 stock cars and 28 mules.

At Upper Mauch Chunk, there were four parallel inclined planes, descending 215 feet in 700. This operation was effected by a cable wound around a drum revolving horizontally, the weight of the loaded car being partially counterpoised by an empty car ascending on a parallel track, and the descent being controlled by a clasp-brake on the drum.

In 1845, animal power was discontinued and the road reconstructed on a different plan with a single plane, rising 664 feet in 2,322 from Upper Mauch Chunk to the top of Mount Pisgah. This plane was operated by two engines, each of 120 horse-power, by which a train was hoisted in eight minutes. A brake-car was attached to each train, with a latch working in a ratchet-rail as an emergency brake.

From Mount Pisgah, the empty trains descended by gravity for six miles, on a gradient of 50 feet to the mile, to the foot of Mount Jefferson, whose summit was then reached by an inclined plane rising 462 feet in 2070, whence the line descended again for a mile to Summit Hill and thence by switchbacks, on a gradient of 221 feet to the mile, to the foot of Panther Creek Plane No. 2, which rose 250 feet in 2030. From the top of this plane, the trains descended again by gravity for several miles to the foot of Panther Creek Plane No. 1, rising 375 feet in 2,436 to a connection at Summit Hill with the switchback of nine miles to Upper Mauch Chunk.

At the switching points, the descending train ascended the stem of a "Y" track until its momentum had been lost. As its motion reversed, the train automatically changed the switch and was directed into the next incline. The switchback west of Summit Hill was abandoned when the mines were connected with the main line of railroad by branch roads. Since 1870, the switchback east of Summit Hill has been used only for excursions between May and November.

This information has been kindly furnished by D. G. Baird, Esq., Secretary Lehigh Valley R. R. Co.

APPENDIX V

Rails, Signals, Yards, Stations, Improvements

Notes and Tables I to XXXI

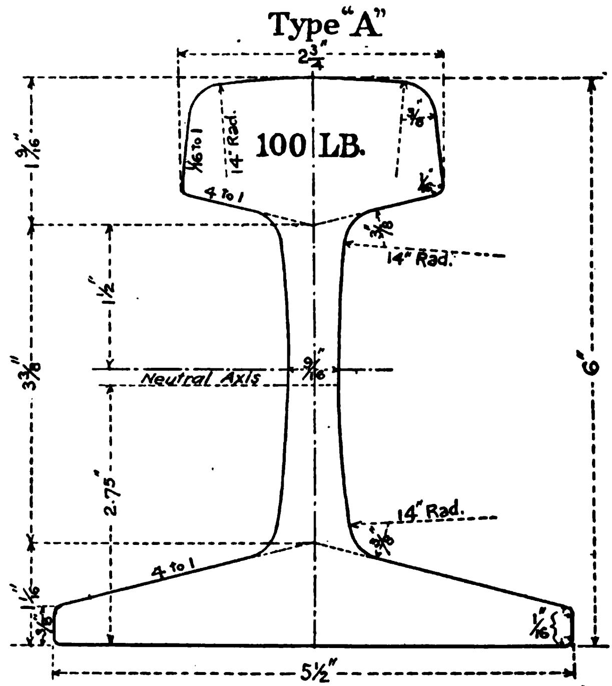
I. Principal Dimensions of Standard Rail Sections

Designation	Type	Weight	Height	Base
		Lbs. per yd.	Ins.	Ins.
American Railway Association	A	60	$4\frac{1}{2}$	4
" " "	B	60	$4\frac{3}{16}$	$3\frac{11}{16}$
" " "	A	70	$4\frac{3}{4}$	$4\frac{1}{4}$
" " "	B	70	$4\frac{35}{64}$	$4\frac{3}{64}$
" " "	A	80	$5\frac{1}{8}$	$4\frac{5}{8}$
" " "	B	80	$4\frac{15}{16}$	$4\frac{7}{16}$
American Railway Engineering Association . . .		89.96	$5\frac{5}{8}$	$5\frac{1}{8}$
American Railway Association	A	90	$5\frac{5}{8}$	$5\frac{1}{8}$
" " "	B	90	$5\frac{17}{64}$	$4\frac{49}{64}$
" " "	A	100	6	$5\frac{1}{2}$
" " "	B	100	$5\frac{41}{64}$	$5\frac{9}{64}$
American Railway Engineering Association . . .		101.49	6	$5\frac{5}{8}$
Lehigh Valley Railroad		110	6	$5\frac{1}{2}$
American Railway Engineering Association . . .		110.36	$6\frac{1}{4}$	$5\frac{1}{2}$
" " " " "		120.87	$6\frac{1}{2}$	$5\frac{3}{4}$
Pennsylvania Railroad		125	$6\frac{1}{2}$	$5\frac{1}{2}$
American Railway Engineering Association . . .		129.64	$6\frac{3}{4}$	6
Central R. R. of New Jersey		135	$6\frac{1}{2}$	6
Lehigh Valley Railroad		136	7	$6\frac{1}{2}$
American Railway Engineering Association . . .		138.52	7	$6\frac{1}{4}$

II. Distribution of Material in Rail Sections

Designation	Type	Weight per Yd.	Per Cent. in Head	Per Cent. in Web	Per Cent. in Base
American Railway Association . . .	A	60 lb.	37.7	24.1	38.2
" " " . . .	B	60 "	38.8	19.4	41.8
" " " . . .	A	70 "	39.3	21.8	38.9
" " " . . .	B	70 "	40.1	19.5	40.4
" " " . . .	A	80 "	38.8	21.0	40.2
" " " . . .	B	80 "	38.8	19.5	41.7
Pennsylvania Railroad		85 "	42.2	17.8	40.0
Canadian Pacific Railroad		85 "	36.77	22.21	41.02
American Railway Engineering Asso'n		89.96 "	36.2	24.0	39.8
American Railway Association . . .	A	90 "	36.2	24.0	39.8
" " " . . .	B	90 "	40.1	19.2	40.7
" " " . . .	A	100 "	36.9	23.4	39.7
" " " . . .	B	100 "	40.2	19.2	40.6
American Railway Engineering Asso'n		101.49 "	38.2	22.6	39.2
" " " "		110.36 "	37.4	23.0	39.6

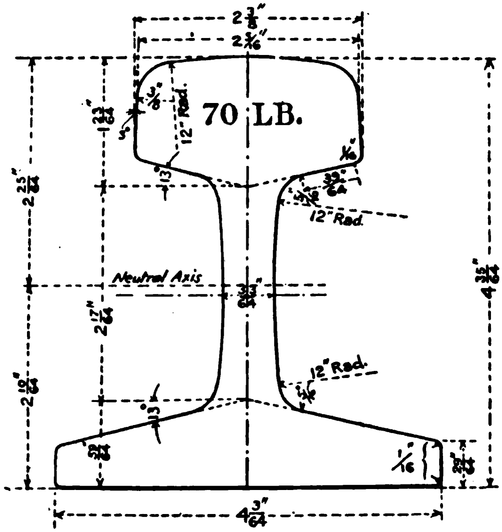
A. R. A. RAIL SECTIONS — *Continued*



Area of Head,	3.64 sq. in.	. . . .	36.9%
" Web,	2.29 "	. . . .	23.4%
" Base,	3.91 "	. . . .	39.7%
Total,	9.84 "	. . . .	100.0%
Ratio Periphery Head to Area Head		. . . .	1.80
" " Web " Web		. . . .	3.21
" " Base " Base		. . . .	3.29
Ratio Total Periphery to Total Area		. . . .	2.92
Moment of Inertia		. . . .	48.94
Section Modulus—Head		. . . .	15.04
" " Base		. . . .	17.78

A. R. A. RAIL SECTIONS — *Continued*

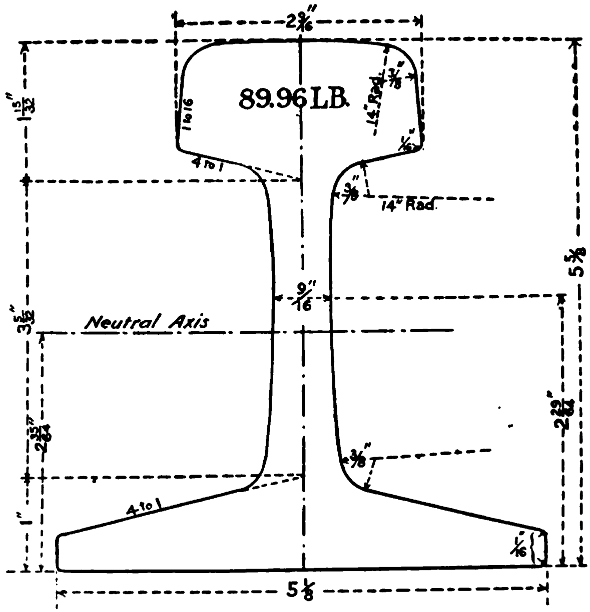
Type "B."



Area of Head,	2.76 sq. in.	40.1%
" Web,	1.34 "	19.5%
" Base,	2.79 "	40.4%
Total,	6.89 "	100.0%
Ratio Periphery Head to Area Head		1.99
" " Web " Web		4.10
" " Base " Base		2.76
Ratio Total Periphery to Total Area		2.72
Moment of Inertia		18.6
Section Modulus—Head		7.79
" " Base		8.62

III. *Continued.* Rail Sections of American Railway Engineering Association

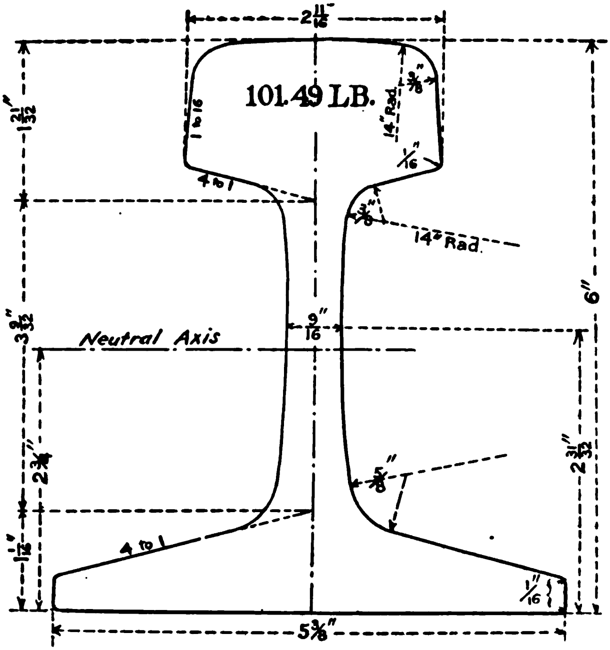
Section Recommended for Approval — A.R.A. — A 90 lb.



Area: Head = 3.20 sq. in.	. . . .	36.2%
Web = 2.12 " "	. . . .	24.0%
Base = 3.50 " "	. . . .	39.8%
Total = 8.82 " "	. . . .	100.0%
Moment of Inertia	. . . .	38.7
Section Modulus—Head	. . . .	12.56
Base	. . . .	15.23
Ratio M. I. to Area	. . . .	4.39
Ratio Sec. Mod. to Area	. . . .	1.42

A. R. E. A. RAIL SECTIONS — *Continued*

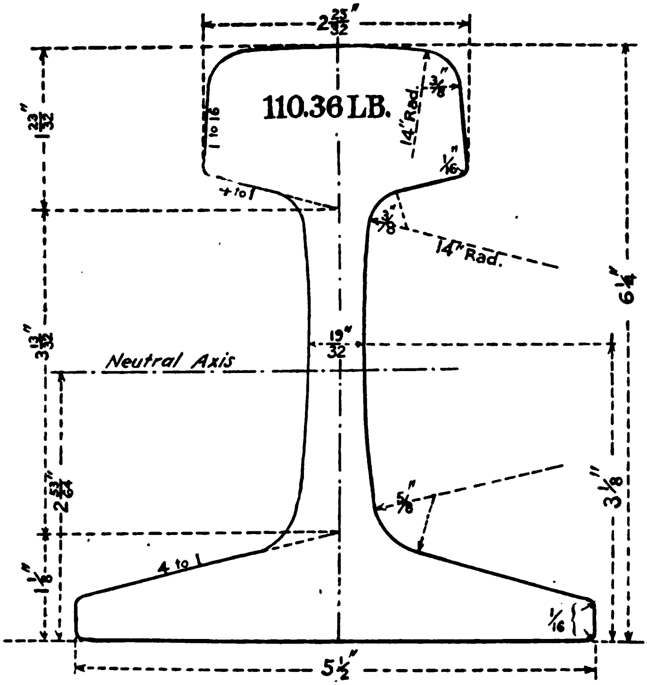
Section Recommended for Approval — A. R. A. — 100 lb.



Area: Head = 3.80 sq. in.		38.2%
Web = 2.25 " "		22.6%
Base = 3.90 " "		39.2%
Total = 9.95 " "		100.0%
Moment of Inertia	49.0	
Section Modulus—Head	15.1	
" " Base	17.8	
Ratio M. I. to Area	4.92	
Ratio Sec. Mod. to Area	1.52	

A. R. E. A. Rail Sections — *Continued*

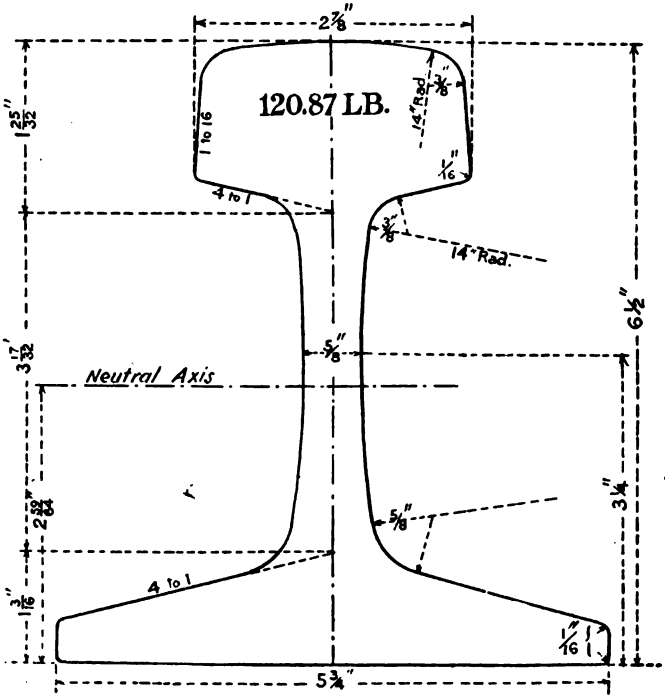
Section Recommended for Approval — A. R. A. — 110 lb.



Area: Head = 4.04 sq. in.	. . . .	37.4%
Web = 2.49 " "	. . . .	23.0%
Base = 4.29 " "	. . . .	39.6%
Total = 10.82 " "	. . . .	100.0%
Moment of Inertia	. . . .	57.0
Section Modulus—Head	. . . .	16.7
" " Base	. . . .	20.1
Ratio M. I. to Area	. . . .	5.27
Ratio Sec. Mod. to Area	. . . .	1.55

A. R. E. A. RAIL SECTIONS — *Continued*

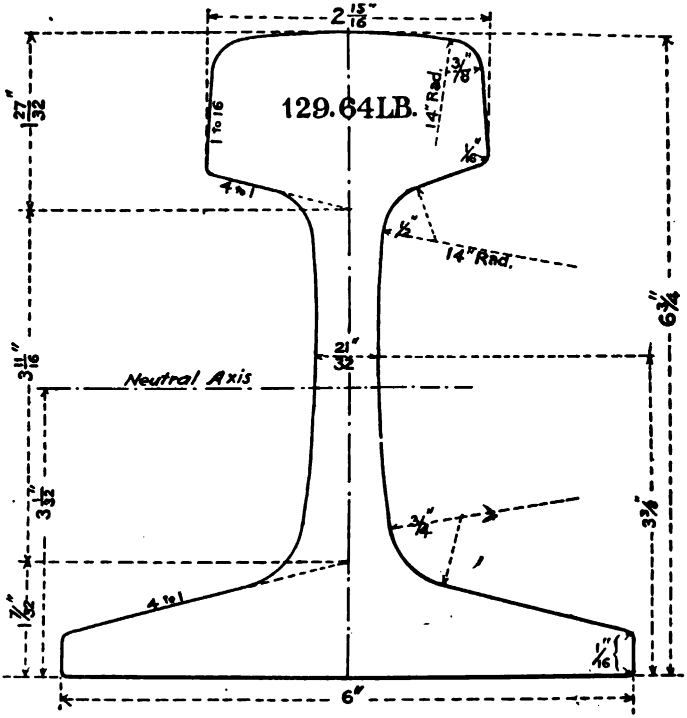
Section Recommended for Approval — A. R A. — 120 lb.



Area: Head = 4.40 sq. in.	. . . .	37.1%
Web = 2.69 " "	. . . .	22.7%
Base = 4.76 " "	. . . .	40.2%
Total = 11.85 " "	. . . .	100.0%
Moment of Inertia	. . . .	67.6
Section Modulus—Head	. . . .	18.9
" " Base	. . . .	23.1
Ratio M. I. to Area	. . . .	5.71
Ratio Sec. Mod. to Area	. . . .	1.59

A. R. E. A. RAIL SECTIONS—*Continued*

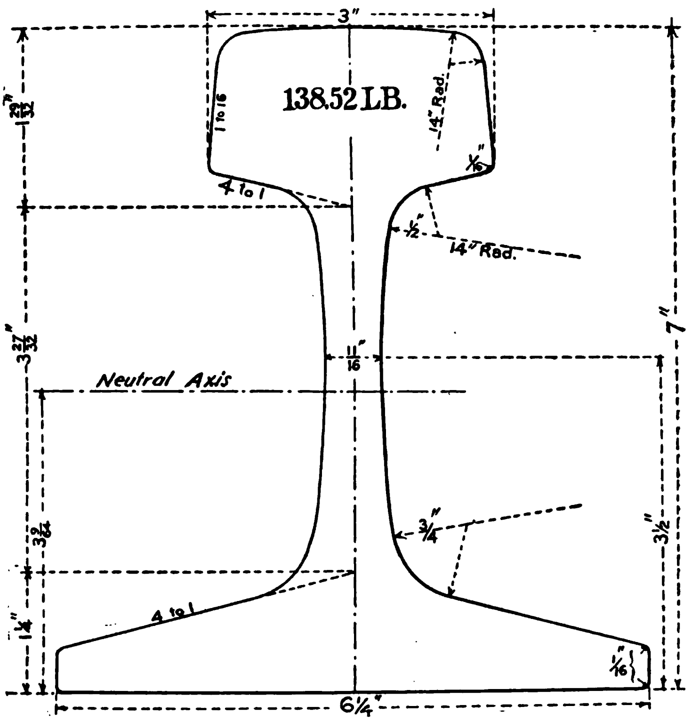
Not Recommended for Approval — 130 lb.



Area: Head = 4.63 sq. in.	. . . .	36.4%
Web = 3.02 " "	. . . .	23.8%
Base = 5.06 " "	. . . .	39.8%
Total = 12.71 " "	. . . .	100.0%
Moment of Inertia	. . . .	77.4
Section Modulus—Head	. . . .	20.8
" " Base	. . . .	25.6
Ratio M. I. to Area	. . . .	6.09
Ratio Sec. Mod. to Area	. . . .	1.64

A. R. E. A. Rail Sections — *Continued*

Not Recommended for Approval — 140 lb.



Area: Head = 4.93 sq. in.		36.3%
Web = 3.28 " "		24.1%
Base = 5.37 " "		39.6%
Total = 13.58 " "		100.0%
Moment of Inertia		89.2
Section Modulus—Head		23.1
" " Base		28.4
Ratio M. I. to Area		6.56
Ratio Sec. Mod. to Area		1.70

IV. Specifications for Carbon Steel Rails

Submitted by American Railway Engineering Association

Provisionally Approved as the Standard of The American Railway Association, November 20, 1912; amended May 20, 1914, approved as "Recommended Practice," November 7, 1915.

INSPECTION

Access to Works.

1. Inspectors representing the purchaser shall have free entry to the works of the manufacturer at all times while the contract is being executed, and shall have all reasonable facilities afforded them by the manufacturer to satisfy them that the rails have been made and loaded in accordance with the terms of the specifications.

Place for Tests.

2. All tests and inspections shall be made at the place of manufacture, prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the mill.

MATERIAL

Material.

3. The material shall be steel made by the Bessemer or Open Hearth process as provided by the contract.

CHEMICAL REQUIREMENTS

Chemical Composition.

4. The chemical composition of each heat of the steel from which the rails are rolled, determined as prescribed in Section 6, shall be within the following limits:

Elements	Per Cent. for Bessemer Process		Per Cent. for Open Hearth Process	
	70 lb. and over, but under 85 lb.	85–100 lb., inclusive	70 lb. and over, but under 85 lb.	85–100 lb., inclusive
Carbon	0.40 to 0.50	0.45 to 0.55	0.53 to 0.66	0.62 to 0.75
Phosphorus not to exceed	0.10	0.10	0.04	0.04
Manganese	0.80 to 1.10	0.80 to 1.10	0.60 to 0.90	0.60 to 0.90
Silicon, not less than . .	0.10	0.10	0.10	0.10

When other acceptable deoxidizing agents are used, the minimum limit for silicon will be omitted.

Average Carbon.

5. It is desired that the percentage of carbon in an entire order of rails shall average as high as the mean percentage between the upper and lower limits specified.

Analyses.

6. In order to ascertain whether the chemical composition is in accordance with the requirements, analyses shall be furnished as follows:

(*a*) For Bessemer process the manufacturer shall furnish to the inspector, daily, carbon determinations for each heat before the rails are shipped, and two chemical analyses every twenty-four hours representing the average of the elements, carbon, manganese, silicon, phosphorus and sulphur, contained in the steel, one for each day and night turn respectively. These analyses shall be made on drillings taken from the ladle test-ingot not less than one-eighth inch beneath the surface.

(*b*) For Open Hearth process, the makers shall furnish the inspectors with a chemical analysis of the elements, carbon, manganese, silicon, phosphorus and sulphur, for each heat.

(*c*) On request of the inspector, the manufacturer shall furnish a portion of the test-ingot for check analyses.

PHYSICAL REQUIREMENTS

Physical Qualities.

7. Tests shall be made to determine:

(*a*) Ductility or toughness as opposed to brittleness.

(*b*) Soundness.

Method of Testing.

8. The physical qualities shall be determined by the drop test.

Drop Testing Machine.

9. The drop testing machine used shall be the standard of the American Railway Engineering Association.

(*a*) The tup shall weigh 2000 pounds, and have a striking face with a radius of five inches.

(*b*) The anvil block shall weigh 20,000 pounds, and be supported on springs.

(*c*) The supports for the test pieces shall be spaced three feet between centers and shall be a part of, and firmly secured to, the anvil. The bearing surfaces of the supports shall have a radius of five inches.

Pieces for Drop Test.

10. Drop tests shall be made on pieces of rail not less than four feet and not more than six feet long. These test pieces shall be cut from the top end of the top rail of the ingot, and marked on the base or head with gauge marks one inch apart for three inches each side of the center of the test piece, for measuring the ductility of the metal.

Temperature of Test Pieces.

11. The temperature of the test pieces shall be between 60 and 100 degrees Fahrenheit.

Height to Drop.

12. The test piece shall preferably be placed base upwards on the supports, and be subjected to impact of the tup falling free from the following heights:

For 70-pound rail	16 feet
For 80, 85 and 90-pound rail	17 feet
For 100-pound rail	18 feet

Elongation or Ductility.

13. (*a*) Under these impacts the rail under one or more blows shall show at least 6 per cent. elongation for one inch, or 5 per cent. each for two consecutive inches of the six-inch scale, marked as described in Section 10.

(*b*) A sufficient number of blows shall be given to determine the complete elongation of the test piece of at least every fifth heat of Bessemer steel, and of one out of every three test pieces of a heat of Open Hearth steel.

Permanent Set.

14. It is desired that the permanent set after one blow under the drop test shall not exceed that in the following table, and a record shall be made of this information:

Rail			Permanent Set, Measured by Middle Ordinate in Inches in a Length of 3 Feet	
Section	Weight per Yard	Moment of Inertia	Bessemer Process	Open Hearth Process
A. R. A.—A	100	48.94	1.65	1.45
A. R. A.—B	100	41.30	2.05	1.80
A. R. A.—A	90	38.70	1.90	1.65
A. R. A.—B	90	32.30	2.20	2.00
A. R. A.—A	80	28.80	2.85	2.45
A. R. A.—B	80	25.00	3.15	2.85
A. R. A.—A	70	21.05	3.50	3.10
A. R. A.—B	70	18.60	3.85	3.50

Test to Destruction.

15. The test pieces which do not break under the first or subsequent blows shall be nicked and broken, to determine whether the interior metal is sound. The words "interior defect," used below, shall be interpreted to mean seams, laminations, cavities or interposed foreign matter made visible by the destruction tests, the saws or the drills.

Bessemer Process Drop Tests.

16. One piece shall be tested from each heat of Bessemer steel.

(*a*) If the test piece does not break at the first blow and shows the required elongation (Section 13), all of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(*b*) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the top rails from that heat shall be rejected.

(*c*) A second test shall then be made of a test piece selected by the inspector from the top end of any second rail of the same heat, preferably of the same ingot. If the test piece does not break at the first blow, and shows the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(*d*) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the second rails from that heat shall be rejected.

(*e*) A third test shall then be made of a test piece selected by the inspector from the top end of any third rail of the same heat, preferably of the same ingot. If the test piece does not break at the first blow and shows the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(*f*) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the remainder of the rails from that heat shall be rejected.

Open Hearth Process Drop Tests.

17. Test pieces shall be selected from the second, middle and last full ingot of each Open Hearth heat.

(a) If two of these test pieces do not break at the first blow, and if both show the required elongation (Section 13), all of the rails of the heat shall be accepted, provided that none of the three test pieces when broken show interior defect.

(b) If two of the test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the top rails from that heat shall be rejected.

(c) Second tests shall then be made from three test pieces selected by the inspector from the top end of any second rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow and if both show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that none of the three test pieces when broken shows interior defect.

(d) If two of these test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the second rails of the heat shall be rejected.

(e) Third tests shall then be made from three test pieces selected by the inspector from the top end of any third rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow, and if both show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that none of the three test pieces when broken show interior defect.

(f) If two of these test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the remainder of the rails from that heat shall be rejected.

No. 1 Rails.

18. No. 1 classification rails shall be free from injurious defects and flaws of all kinds.

No. 2 Rails.

19. (a) Rails which, by reason of surface imperfections, or for causes mentioned in Section 29 hereof, are not classed as No. 1 rails will be accepted as No. 2 rails, but No. 2 rails which contain imperfections in such number or of such character as will, in the judgment of the inspector, render them unfit for recognized No. 2 uses will not be accepted for shipment.

(b) No. 2 rails to the extent of 5 per cent. of the whole order will be received. All rails accepted as No. 2 rails shall have the ends painted white and shall have two prick-punch marks on the side of the web near the heat number near the end of the rail, so placed as not to be covered by the splice bars.

DETAILS OF MANUFACTURE

Quality of Manufacture.

20. The entire process of manufacture shall be in accordance with the best current state of the art.

Bled Ingots.

21. Bled ingots shall not be used.

Discard.

22. There shall be sheared from the end of the bloom, formed from the top of the ingot, sufficient metal to secure sound rails.

Lengths.

23. The standard length of rails shall be 33 feet, at a temperature of 60 degrees Fahrenheit. Ten per cent. of the entire order will be accepted in shorter lengths varying by 1 foot from 32 feet to 25 feet. A variation of one-fourth inch from the

specified lengths will be allowed, excepting that for 15 per cent. of the order a variation of three-eighths inch from the specified lengths will be allowed. No. 1 rails less than 33 feet long shall be painted green on both ends.

Shrinkage.

24. The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass, the temperature of the rail will not exceed that which requires a shrinkage allowance at the hot saws, for a rail 33 feet in length and of 100-pound section, of six and three-fourths inches and one-eighth inch less for each ten pounds decrease in section.

Cooling.

25. The bars shall not be held for the purpose of reducing their temperature, nor shall any artificial means of cooling them be used after they leave the finishing pass. Rails, while on the cooling beds, shall be protected from snow and water.

Section.

26. The section of rails shall conform as accurately as possible to the template furnished by the railroad company. A variation in height of one-sixty-fourth inch less or one-thirty-second inch greater than the specified height, and one-sixteenth inch in width of flange, will be permitted; but no variation shall be allowed in the dimensions affecting the fit of the splice bars.

Weight.

27. The weight of the rails specified in the order shall be maintained as nearly as possible, after complying with the preceding section. A variation of one-half of one per cent. from the calculated weight of section, as applied to an entire order, will be allowed.

Payment.

28. Rails accepted will be paid for according to actual weights.

Straightening.

29. (*a*) The hot straightening shall be carefully done, so that gagging under the cold presses will be reduced to a minimum. Any rail coming to the straightening presses showing sharp kinks or greater camber than that indicated by a middle ordinate of 4 inches in 33 feet, for A. R. A. type of sections, or 5 inches for A. S. C. E. type of sections, will be at once classed as a No. 2 rail. The distance between the supports of rails in the straightening presses shall not be less than 42 inches. The supports shall have flat surfaces and be out of wind.

(*b*) Rails heard to snap or check while being straightened shall be at once rejected.

Drilling.

30. Circular holes for joint bolts shall be drilled to conform to the drawing and dimensions furnished by the railroad company. A variation of one-thirty-second inch in excess in size of holes will be allowed.

Finishing.

31. (*a*) All rails shall be smooth on the heads, straight in line and surface, and without any twists, waves or kinks. They shall be sawed square at the ends, a variation of not more than one-thirty-second inch being allowed; and burrs shall be carefully removed.

(*b*) Rails improperly drilled or straightened, or from which the burrs have not been removed, shall be rejected, but may be accepted after being properly finished.

(*c*) When any finished rail shows interior defects at either end or in a drilled hole, the entire rail shall be rejected.

Branding.

32. Rails shall be branded for identification in the following manner:

"(*a*) The name of the manufacturer, the month and year of manufacture and the weight and type or section of rail shall be rolled in raised letters and figures on the side of the web. The type shall be marked by letters which signify the name by which it is known, as for example:

Sections of American Society of Civil Engineers	A. S. C. E.
Sections of American Railway Association	R. A.–A. / R. A.–B.
Sections of American Railway Engineering Association . .	R. E.

"(*b*) The number of the heat and letter indicating the portion of the ingot from which the rail was made shall be plainly stamped on the web of each rail where it will not be covered by the joint bars. The top rails shall be lettered 'A,' and the succeeding ones 'B,' 'C,' 'D,' etc., consecutively; but in case of a top discard of from 20 to 35 per cent., the letter 'A' will be omitted, the top rail becoming 'B.' If the top discard be greater than 35 per cent., the letter 'B' shall be omitted, the top rail becoming 'C.'

"(*c*) Open Hearth rails shall be branded or stamped 'O-H' in addition to the other marks.

"(*d*) All markings of rails shall be done so effectively that the marks may be read as long as the rails are in service."

Separate Classes.

33. All classes of rails shall be kept separate from each other.

Loading.

34. All rails shall be loaded in the presence of the inspector.

V. American Railway Association's Specifications for High-carbon Steel Joint-Bars

Adopted as "Recommended Practice," November 17, 1915

Basis of Purchase.

1. Inspectors representing the purchaser shall have free entry to the works of the manufacturer at all times while the contract is being executed, and shall have all reasonable facilities afforded them by the manufacturer to satisfy them that the joint-bars have been made in accordance with the terms of the specifications.

2. All tests and inspection shall be made at the place of manufacture prior to loading, and shall be so conducted as not to interfere unnecessarily with the operation of the mill.

Material.

3. Material for joint-bars shall be steel, made by the Open Hearth process.

Chemical Properties.

4. The chemical composition of each melt of steel from which joint-bars are manufactured shall be within the following limits:

Phosphorus, per cent., maximum, 0.04.

5. The manufacturer shall furnish the inspector a complete report of ladle analysis, showing carbon, manganese, phosphorus and sulphur content of each melt represented in the finished material. The purchaser may make a check analysis from the finished material; such analysis shall conform to the requirements in Section 4.

Physical Properties and Tests.

6. Joint-bars shall conform to the following physical requirements:

(*a*) Tensile strength, pounds per square inch, minimum, 85,000.

(*b*) Elongation, per cent. in 2 inches, minimum, 16.

(*c*) Cold bending without fracture on the outside of the bent portion through 90 degrees around an arc the diameter of which is three times the thickness of the test piece.

7. All test pieces shall be cut from finished bars.

(*a*) Standard ½-by-2-inch specimens, as adopted by the American Society for Testing Materials, shall be used for tension test.

(*b*) The bend test specimens shall be ½ inch square in section, or a rectangular bar ½ inch thick, with two parallel faces as rolled.

General Requirements.

8. The different sections of joint-bars shall be rolled to dimensions specified in drawing furnished by the purchaser. No variation will be allowed in the dimensions affecting the fit and the fishing spaces of the rail. The maximum camber on either plant shall not exceed $\frac{1}{32}$ inch in 24 inches.

9. The joint-bars shall be sheared to the length prescribed by the purchaser and shall not vary therefrom by more than ¼ inch.

10. (*a*) All joint-bars shall be punched, slotted and shaped at a temperature of not less than 800 degrees Centigrade (1470 degrees Fahrenheit).

(*b*) All bolt-holes shall be punched in one operation, without bulging or distorting the section, and the bars shall be slotted for spikes, when required, in accordance with the drawings, the slotting being done in one operation; a variation of $\frac{1}{32}$ inch in the size and location of the holes will be allowed.

11. All joint-bars must be finished smooth and true, without swelling over or under the bolt holes, and be free from flaws, seams, checks or fins, and the fishing angles must be fully maintained.

12. The manufacturer's identification symbol, kind of material, month and year rolled and number of design, shall be rolled in raised letters and figures on each bar. The number of the melt shall be plainly stenciled on each lot of joint-bars.

Inspection.

13. The joint-bars from each melt shall be piled separately until tested and inspected by the purchaser's inspector. One joint-bar for tension test shall be selected by the inspector for each melt represented in finished bars, or by agreement specimen for tension test may be cut from the bar as rolled. One joint-bar for bend test shall be selected by the inspector for each lot of 1000 bars or less presented.

Specifications for Heat-Treated, Oil-quenched, Steel Joint-bars

Basis of Purchase.

1. Inspectors representing the purchaser shall have free entry to the works of the manufacturer at all times while the contract is being executed, and shall have all reasonable facilities afforded them by the manufacturer to satisfy them that the joint-bars have been made and loaded in accordance with the terms of the specifications.

2. All tests and inspection shall be made at the place of manufacture prior to shipment and shall be so conducted as not to interfere unnecessarily with the operation of the mill.

Material.

3. Material for joint-bars shall be steel, made by the Open Hearth process.

Chemical Properties.

4. The chemical composition of each melt of steel from which joint-bars are manufactured shall be within the following limits:

Phosphorus, per cent., maximum, 0.04.

5. The manufacturer shall furnish the inspector a complete report of ladle analysis, showing carbon, manganese, phosphorus and sulphur content of each melt represented in the finished material. The purchaser may make check analysis from the finished material; such analysis shall conform to the requirements in Section 4.

Physical Properties and Tests.

6. Joint bars shall conform to the following physical requirements:

(*a*) Tensile strength, pounds per square inch, minimum, 100,000.

(*b*) Yield point, pounds per square inch, minimum, 70,000.

(*c*) Elongation, per cent. in 2 inches not less than $\frac{1{,}500{,}000}{\text{Ten. str.}}$ minimum, 12.

(*d*) Cold bending without fracture on the outside of the bent portion through 90 degrees around an arc, the diameter of which is one and one-half times the thickness of test piece.

7. All test pieces shall be cut from finished bars.

(*a*) Standard ½-by-2-inch specimens, as adopted by the American Society for Testing Materials, shall be used for tension test.

(*b*) The bend test specimens shall be ½ inch square in section, or a rectangular bar ½ inch thick with two parallel faces as rolled.

Heat Treatment.

8. Joint-bars shall be heated and quenched in an oil bath from a temperature of about 810 degrees Centigrade (1490 degrees Fahrenheit), and shall be kept in the oil bath until cold enough to be handled.

General Requirements.

9. Joint-bars shall be rolled to dimensions specified in drawing furnished by the purchaser. No variation will be allowed in the dimensions affecting the fit and the fishing spaces of the rail. The maximum camber in either plane shall not exceed $\frac{1}{32}$ inch in 24 inches.

10. Joint-bars shall be sheared to the length prescribed by the purchaser and shall not vary therefrom by more than ¼ inch.

11. (*a*) All joint-bars shall be punched, slotted and shaped at a temperature of not less than 800 degrees Centigrade (1470 degrees Fahrenheit).

(*b*) All bolt-holes shall be punched in one operation without bulging or distorting the section, and the bars shall be slotted, when required, for spikes in accordance with the purchaser's drawing, the slotting being done in one operation. A variation of $\frac{1}{32}$ inch in size and location of the holes will be allowed.

12. All types of joint-bars must be finished smooth and true without swelling over or under the bolt-holes, and be free from flaws, seams, checks or fins. The fishing angles must be fully maintained.

13. The manufacturer's identification symbol, kind of material, month and year rolled, number of design, and the letters "HT" to signify heat-treated, shall be rolled in raised letters and figures on each bar. The number of the melt shall be plainly stenciled on each lot of joint-bars.

Inspection.

14. The joint-bars from each melt or heat-treatment lot shall be piled separately until tested and inspected by the inspector. One joint-bar for tension test

shall be selected by the inspector for each melt or heat-treatment lot represented in finished bars. One joint-bar for bend test shall be selected by the inspector for each lot of 1000 bars or less presented, or from each heat-treatment lot.

VI. Specifications for Joint-Bars. Lehigh Valley and Pennsylvania Railroads

The specifications for the joint-bars for the 136-pound rail for the *Lehigh Valley Railroad* require them to be 26 inches long, with six bolt-holes, spaced 4 inches between centers. Bolts $1\frac{1}{16}$ inches diameter in the shank, with rolled thread $1\frac{1}{8}$ inches diameter; neck and head oval. Square nuts and spring-locks. Bolts placed with heads and nuts alternately inside of rail. Bolt-holes in bars alternately, $1\frac{3}{16}$ inches diameter, and $1\frac{3}{16}$ inches by $1\frac{1}{2}$ inches oval. Bolt-holes in rails $1\frac{5}{16}$ inches diameter.

The specifications for joint-bars for the 100-pound rail for the *Pennsylvania Railroad* require them to be 26 inches long, heavily ribbed, with inclined flanges extending inward beneath the rail, — slotted for spikes. Four bolt-holes, spaced 5 inches for inner and 7 inches for outer bolts. Bolt-heads alternately on inner and outer sides of joint. This bar requires adjustment of ties to fit joints, and compels some displacement of ballast.

VII. Output of Bessemer and Open Hearth Rails
(American Iron and Steel Association)

Year	Bessemer	Open Hearth	Electric and Re-rolled	Total
	Tons	Tons	Tons	Tons
1900	2,383,654	1,333		2,384,987
1901	2,870,816	2,093		2,872,909
1902	2,935,392	6,029		2,941,421
1903	2,946,756	45,054		2,991,810
1904	2,137,957	145,883		2,283,840
1905	3,192,347	183,264		3,375,611
1906				3,977,887
1910				3,636,031
1911				2,822,790
1912	1,099,926	2,105,144	122,845	3,327,915
1913	817,591	2,723,369		3,540,960

VIII. Statistics of Rail Failures

Rail Failures during the Year ending October 31, 1911. (American Railway Engineering Association)

Rails in Service	Bessemer	Open Hearth	Total
Total tons (2240 lb.)	10,088,706	2,600,008	12,688,714
No. of Rails — 30-ft. lengths	27,866,348	6,622,736	34,489,084
Rail Failures	**Bessemer**	**Open Hearth**	**Total**
Broken	8,165	1,786	9,951
Head	17,761	2,260	20,021
Web	2,450	515	2,965
Base	2,898	806	3,704
Total	31,274	5,367	36,641
Failures per 1000 tons of rails in service			
Broken	8.1	6.9	7.9
Head	17.6	8.7	15.8
Web	2.4	2.0	2.4
Base	2.9	3.1	2.9
Total	31.0	20.7	29.0
Percentage of failures			
Broken	26	33	27
Head	57	42	55
Web	8	10	8
Base	9	15	10
No. of rails per failure	891	1,234	941

Broken rails on principal lines in the State of New York were reported to the State Commission as follows:

During the period of three months ending March 31, there were, in 1905, 1331 rail-failures; in 1906, 826; and in 1907, 3014. The broken rails in 1905–1906 were chiefly of an 80-pound section; and in 1907, of a 100-pound section. Rails that were laid in 1872 are still in use, principally on branch lines.

Failures caused by wheel-defects. The Railway Age Gazette of March 16, 1910, reported that 200 rails of 85-pound section were broken in 14 miles by a wheel with a 6-inch flat spot. During severe winter weather in January and February, 1912, many rails on lines in the Northwest were broken by flat wheels. On a line in Minnesota, a 4-inch flat spot on a rolled-steel wheel in passenger-service broke nine 80-pound rails in a distance of three miles. On a line in Illinois, a 5½-inch flat-spot on a steel-tired wheel broke 150 rails in a short distance. On a line in South Dakota, two steel wheels under a dining-car broke 500 rails. A "shelled out" steel-tired wheel on a fast train in Ohio broke 960 rails in 200 miles. On a line in Indiana, a steel-tired wheel under a baggage-car broke 50 rails in 70 miles.

A defective driving-wheel tire broke over 100 rails on one trip and an equal number on the next, before the cause was definitely located.

In fourteen years, to 1913, inclusive, 3345 *accidents from broken rails* resulted in the death of 205 persons, and in property-loss estimated at $4,000,000.

IX. Spacing of Joints and Sleepers. British Railways

Compiled from "Modern Permanent Way," C. J. Allen, 1915

Railways	L.&N.W.	Gt. W.	N. E. (Branches)	Gt. So. & W. (Ireland)
Distance between joint-ties — inches	12	15 1/12	16	11½
Length of fish-plates "	18	20		18
Weight of rail per yard — pounds	95	97½		87
Length of rail — feet	60	44¼	30	45
Width of joint-sleepers — inches	12	10	12	12
No. of sleepers under rail	24	18	11	18
Spacing between centers:				
Joint-sleeper to next — inches	27¼	25⅞	30	31 1/16
Other sleepers "	30	30½	34	31 1/16

All suspended joints. Staggered joints on Great So. & W. Ry. (Ireland).

X. Wheel-base and Driving-wheel Loads. American Locomotives

Compiled from Locomotive Dictionary, 1912. Am. Ry. M. M. Asso'n

Type	Wheel Arrangement	Wheel-base — Ft.		Weight — Lb.		Driving-wheel Loads — Pounds
		Rigid	Total	Drivers	Total	
Switcher	0–6–0	12′–0″	12′–0″	176,500	176,500	29,417
"	0–8–0	16–0	16–0	229,000	229,000	28,625
"	0–10–0	19–0	19–0	274,000	274,000	27,400
Consolidated	2–8–0	17–0	27–9½	211,000	238,000	26,388
Mikado	2–8–2	16–0	34–8	204,450	263,000	25,557
"	2–8–2	16–6	34–10	243,000	315,000	30,375
Santa Fé	2–10–2	20–9	39–8	301,800	378,700	30,180
Atlantic	4–4–2	6–10	32–8	112,125	231,675	28,032
Pacific	4–6–2	13–0	34–8	166,200	263,800	27,700
"	4–6–2	14–0	36–6	171,500	269,000	28,584
12-wheel	4–8–0	16–0	27–1	213,200	261,100	26,850
Mountain	4–8–2	16–6	37–5	239,000	330,000	29,875
Articulated	0–6–6–0	10–2	31–2	352,000	352,000	29,334
"	0–8–8–0	14–6	40–8	468,500	468,500	29,258
"	2–8–8–2	15–6	57–5	435,500	483,000	27,219
"	2–8–8–2	15–6	57–4	479,200	540,000	29,950
"	2–10–10–2	19–8	66–5	550,000	616,000	27,500

Note. — The most powerful locomotive in the world, up to 1916, is in service on the Erie R. R. It is of the articulated type — (2–8–8–8–2), one group of driving wheels serving as the front truck of the tender. Rigid wheel-base, 16 ft. 6 in. Total driving-wheel base, 71 ft. 6 in. Total wheel-base, locomotive and tender, 90 ft. Load on drivers, 761,000 lb. Total weight, 853,050 lb., tender loaded. Average driving-wheel load, 31,734 lb.

XI. Line Mileage of Various Gauges in 1910. Great Britain and Ireland

(Railway Year Book. 1912)

Gauge	1′–11½″	2′–3″	2′–4″	2′–4½″	2′–6″	2′–9″	3′–0″	3′–6″	4′–0″	4′–6″	4′–8½″	5′–3″	Total
England and Wales .	63	18	3	9	21	7	16	7	14	11	15,993		16,162
Scotland . .		6							7		3,825		3,838
Ireland . .							525					2,867	3,392
	63	24	3	9	21	7	541	7	21	11	19,818	2,867	23,392

Also the Listowel and Ballybunion Railroad, Ireland. Single elevated rail, 9 miles.

XII. Track Mileage in the United States, 1908–1914

Compiled from reports of Interstate Commerce Commission

Year	Line Mileage	Second Track	Third Track	Additional Tracks	Yard Tracks and Sidings	Total Trackage
1908	230,494	20,209	2,081	1,409	79,453	333,645
1909	235,402	20,949	2,170	1,454	82,377	342,351
1910	240,831	21,659	2,206	1,489	85,582	351,766
1911	246,238	23,451	2,414	1,747	88,973	362,824
1912	249,852	24,952	2,512	1,903	92,019	371,238
1913	253,470	26,274	2,589	1,964	95,211	379,508
1914	256,547	27,609	2,696	2,071	98,285	387,208
Increase 1908–14 .	26,053	7,400	615	662	18,832	53,563
Per cent.	11.3	36.6	29.5	47.0	23.7	16.0

The figures for single track include duplication of mileage under traffic rights.

XIII. Comparative Increase of Track Mileage from 1911 to 1914 in the Territorial Traffic Districts

Trackage	Eastern District		Southern District		Western District		United States	
	1911	1914	1911	1914	1911	1914	1911	1914
Line Mileage . .	64,038	64,941	47,153	49,670	135,046	141,936	246,238	256,547
Second Track . .	14,889	16,364	2,464	3,149	6,098	8,095	23,451	27,608
Third " . .	2,193	2,420	89	44	195	232	2,414	2,696
Additional " . . .	1,535	1,771	26	157	123	144	1,747	2,072
Total	82,655	85,496	49,732	53,020	141,462	150,407	273,850	288,923
Yards and Sidings .	36,894	40,059	13,925	15,729	38,155	42,496	88,974	98,284
Total	119,549	125,555	63,657	68,749	179,617	192,903	362,824	387,207

XIV. Distribution of Track Mileage in Territorial Traffic Districts, 1914

Trackage	Eastern District	Southern District	Western District
	Per Cent.	Per Cent.	Per Cent.
Line Mileage	25.3	19.4	55.3
Second Track	59.3	11.4	29.3
Additional Tracks	87.8	4.2	8.0
Total Running Tracks	29.6	18.4	52.0
Yard Tracks and Sidings	40.8	16.0	43.2
Proportion of Sidings to Running Tracks	47.0	21.0	28.0

XV. Trackage Facilities in Eastern Territorial District, U. S., in 1914, and in England and Wales in 1910

	Eastern District		England and Wales	
	Per Square Mile	Per 10,000 Population	Per Square Mile	Per 10,000 Population
Line Mileage	0.17	15.0	0.25	4.13
Running Tracks	0.23	20.0	0.46	7.56
Yards and Sidings	0.11	9.3	0.20	3.23
Total Trackage	0.34	29.3	0.66	10.79

XVI. Track Mileage in Great Britain and Ireland

Lines having less than 100 miles not included

Compiled from Railway Year Book, 1912

	Line Mileage	Second Track	Third Track	Additional Tracks	Running Tracks	Yards and Sidings	Total Trackage
England and Wales	14,888	10,090	1,344	1,092	27,414	11,641	39,055
Scotland	3,721	1,574	64	36	5,395	2,245	7,640
Ireland	2,757	649	6	4	3,416	446	3,862
Total	21,366	12,313	1,414	1,132	36,225	14,332	50,557
All Lines	23,389	13,189	1,517	1,756	39,851	14,460	54,311

XVII. Block System in the United States

Compiled from reports of Interstate Commerce Commission

Year. Jan'y 1st	Automatic				Non-automatic				Total, All Kinds	Total Mileage Passenger Lines	Per Cent. Under Block
	Single Track	Double Track	Three and Four Tracks	Total	Single Track	Double Track	Three and Four Tracks	Total			
1908	4,363	5,700	750	10,803	38,517	8,447	911	47,875	58,678	151,455	39
1909	5,126	6,312	752	12,190	38,407	8,048	903	47,358	59,548	161,451	37
1910	6,278	7,049	910	14,237	42,843	7,822	855	51,520	65,757	162,526	40
1911	8,312	8,225	1,174	17,711	44,897	7,913	757	53,557	71,268	172,389	41
1912	9,314	9,843	1,178	20,335	47,067	8,395	612	56,074	76,409	176,844	43
1913	10,128	10,929	1,362	22,219	52,834	8,367	530	61,731	83,950	183,460	45
1914	11,887	12,956	1,726	26,569	52,030	7,756	381	60,167	86,736	185,986	46

XVIII. Kinds of Automatic Signals — Miles of Line

Year	Disk	Semaphore Signals				Total Automatic
		Electro-pneumatic	Electro-motor	Electro-gas	Total	
1908	2,335	417	7,144	923	8,484	10,819
1909	2,173	411	8,665	925	10,001	12,174
1910	2,223	419	10,664	876	11,959	14,182
1911	2,244	433	14,168	919	15,520	17,764
1912	2,121	424	16,849	906	18,179	20,300
1913	1,932	434	18,930	902	20,267	22,199
1914	1,744	430	23,830	518	24,778	26,522

XIX. Apparatus used with Manual Block System — Miles of Road

Year	Telegraph	Telephone	Electric Bells	Total	Electric Train-staff
1908	40,040	3,287	838	44,165	234
1909	38,074	5,644	858	44,576	261
1910	39,477	8,105	945	48,527	270
1911	38,612	12,199	486	51,297	345
1912	37,417	16,544	511	54,472	400
1913	38,106	23,002	814	61,922	478
1914	33,936	26,241	449	60,625	409

XX. Progressive Development of Block Systems and of Interlocking Apparatus

MANUALLY-CONTROLLED BLOCK SIGNALS

1842. Sir W. F. Cooke proposed a telegraph block system.

1844. Eastern Counties Railway Company used block system and abandoned it as too expensive.

1851. South Eastern Railway Company used electric bell calls for signaling from station to station.

1854. London & North Western Railway Company introduced a block system with visual indicators.

1864. Space interval established on line between New York and Philadelphia.

1876. Metropolitan Railway (London) operated by a block system with 3½-minute intervals.

1882. First manually-controlled system in America on New York Central Railroad.

1884. First single-track block system in America on Canadian Pacific Railway.

AUTOMATIC BLOCK SIGNALS

1871. Hall's inclosed disk on Eastern Railroad, Massachusetts.

1872. Closed track-circuit, William Robinson.

1879. First track-circuit automatic block signals (clock-work), Fitchburg Railroad.

1885. First electro-pneumatic block signals.

1891. First extensive automatic block signal system on single-track. Cincinnati, New Orleans & Texas Pacific Railroad.

1899. Second automatic installation on single-track. Chicago & Alton Railroad.

1915. Single-track automatic block signals on 4466 miles of line. Union Pacific and Southern Pacific Railways.

INTERLOCKING APPARATUS

1846. Signal and switch levers concentrated in England.

1856. Saxby interlocking levers.

1873. 13,000 levers on London & North Western Railway.

1874. First interlocking machine in America at Spuyten Duyvil, N. Y.

1877. First extensive use of interlocking in America on Manhattan Elevated Railway.

1884. First pneumatic interlocking apparatus at Bound Brook, N. J.

1890. First all-electric interlocking apparatus.
First electro-pneumatic interlocking apparatus.

1891. 18 hydro-pneumatic plants, 482 levers.

1894. 46 electro-pneumatic plants, 1600 levers.

1913. 440 all-electric plants, 21,370 levers.

1915. Pennsylvania Eastern and Western lines, 20,000 levers.

"Landmarks in Signaling History." B. H. Mann, Engineers' Club, St. Louis, April 12, 1916. Railway Age Gazette, July 28, 1916.

XXI. Snowsheds. Southern Pacific Company's Lines

The first snowsheds were built with steep roofs, which were often thrown out of line by the unbalanced weight of snow on one side or the other, and especially on side-hill work; even when the shed had been anchored to the hillside by iron rods. Where practicable, the roof was then extended into the adjacent bank to prevent the wedging-in of the snow between the shed and the hillside, and as a precaution against avalanches. This type of shed is in extensive use at the present time, and is commonly known as a "gallery" shed.

The gallery shed suggested the present typical shed, which has a flat roof and is wider at the top than at the bottom. By sloping the sides of the shed outward from the bottom to top in this manner, it was found that the wedging effect of melting snow between the bank and the shed was materially reduced. With this construction, the overhead clearance has been increased from twenty-two to twenty-four feet in order to diminish the hazard from fire. As a further precaution, spark-deflectors are attached to the stacks of the locomotives.

These precautions do not, however, eliminate the danger from brush-fires in the dry season. These are guarded against by a system of watching stations, fire-trains and telephone communication. On the Central Pacific Railroad, at the summit of the Sierras, there are seven watching stations in a distance of twenty-five miles. At the Red Mountain Station, several miles from the track and about two thousand feet above it, nearly the entire line of sheds is visible. This station communicates by telephone with three stations on the line where fire-trains are held in readiness throughout the year, an additional train being maintained during the dry season. Notwithstanding these precautions, a fire would sometimes gain headway from the draft through the shed and destroy several miles of it before being checked.

The danger from fire was almost entirely eliminated by opening gaps at intervals in the line of sheds, which were closed during the period of snowstorms by sections of "telescope" sheds at intervals of 2000 to 2500 feet. These telescope or movable sheds are in sections of fifty feet, running on wheels on a track of 16 feet 8 inch gauge, the rails being supported on sills. The movable sections are run inside of the stationary sections during the summer. In the winter they are hauled into position by block and tackle, and extra braces are bolted on, to secure them in place. This precaution has proven so successful that there are now some twenty of these sections in use on the Southern Pacific lines.

For the period from 1902 to 1910, which may be considered representative, the average annual cost per mile for maintaining the 29.28 miles of snowsheds on these lines was approximately $5900, including repairs and renewals, cost of fire-trains, patrolmen, observers and all other expenses in connection with protection against fire.

(Information furnished by John D. Isaacs, Consulting Engineer, Southern Pacific Company.)

XXII. Gravity Yards. Norfolk & Western Railway

Upon the Norfolk & Western Railway, all coal cars are weighed and classified in gravity yards. The classification of empty cars for movement into the mines is also made in these yards. Loaded cars eastbound are classified at Bluefield, W. Va., at the apex of a grade of about 1.25 per cent. in each direction for a distance of about three miles. There is a separate receiving yard for westbound trains, which are largely composed of empty cars. About 1000 cars in each direction can be classified daily with four locomotives. A "car rider" handles about 39 cars in ten hours.

Westbound coal-trains are made up at Portsmouth, Ohio, in a hump-yard with twenty storage tracks. From 1200 to 1300 loaded cars are classified daily in trains of 75 to 100 cars, with two Mallet locomotives and thirty car-riders, working only by day. Merchandise-trains are passed through the yard on a separate lead and with special storage-tracks.

(Information furnished by N. D. Maher, President.)

XXIII. Sorting Yards

A. In Europe

Country	Location	Area Acres	Miles of Tracks			Car Capacity Daily
			Main Line	Sidings	Total	
France	Lumes (Charleville)	133.9			23.92	2,000
Germany	Mannheim	538.7			95.32	8,000
	Nuremburg	370.7			68.35	4,200
	Hausbergen (Strassburg)	252.3			52.82	4,500
	Brockau	217.2	7.30	54.59	61.89	6,500
	Wilhelmsburg (Hamburg)	137.4	6.62	19.70	26.32	3,500
	Rothensburgort (Hamburg)	101.3	4.35	30.76	35.11	1,800
	Osterfeld (Essen)	123.3	7.00	52.99	59.99	6,655

B. In United States

Railroad	Location	Area Acres	Miles of Tracks	Car Capacity Daily
New York Central	Gardenville, N. Y.	700	300	10,000
	De Witt, N. Y.	250	122	4,400
Pennsylvania	Northumberland	342	69	
	Enola	267	72	
Pennsylvania Lines West	Conway	124	88	
Illinois Central	Nonconnah	160	26	788
Chicago, Burlington & Quincy	Galesburg	148	57	
Boston & Albany	Springfield	130	51	1,125
Union Pacific	Council Bluffs	123	89	
Baltimore & Ohio	Brunswick	114	36	

XXIV. New York Central R. R. Freight Yard — Gardenville

For Buffalo Territory — Car-capacity of body-tracks

[Proceedings International Railway Congress. Berne, 1910.]

Character of Yard	Eastbound Cars	Westbound Cars	Total
Receiving	2,000	2,000	4,000
Classification	3,321	3,195	6,416
Re-classification	530	530	1,060
Transfer	325	325	650
Grouping	231	231	462
Icing	300		300
Car-repair	590	590	1,180
Cripple-hold	190	220	410
Assembly	344	344	688
Fuel coal	153	145	298
Caboose	86	86	172
Tonnage advance	2,000	2,000	4,000
Symbol advance	290	290	580
Drop and pick-up advance	400	400	800
Miscellaneous	195	195	390
Total	10,855	10,551	21,406

ENGINE YARDS — NUMBER OF LOCOMOTIVES

Engine Houses	70	70	140
Incoming Standing Tracks	47	47	94
Outgoing " "	16	16	32
Total	133	133	266

Receiving Yards — 20 tracks, 100 cars each.
Hump-leads from receiving yards:
For interchange with minor connections.
" Buffalo deliveries and transfers.
" interchange with principal connections.
" symbol time-freight.
" symbol drop-trains.
" N. Y., Chi. & St. L. R. R. Total, 5195 cars.
Two grouping yards.
Car-transfer yard.
Hold-yard for cripples.
Main assembly tracks. Westbound Buffalo local movement.
Westbound classification yard, preceded by a hump.
Westbound advance yard.
Westbound symbol advance yard.
Eastbound arrangement on similar lines.

XXV. PRINCIPAL PASSENGER TERMINAL STATIONS

City	Station	Area Acres	No. of Tracks	Length, Miles	No. of Platforms	Trains Daily	Passengers, Daily Average
UNITED STATES							
Boston	South	92	32	15.0	23	817	105,000
	North		23		11	750	80,000
Chicago	Union	35.0	22		12	279	35,000
	Chi. & N. W.	8.0	16	2.7	8	310	50,000
Jersey City	C. R. R. of N. J.		20	3.0	10		
Kansas City	Union	5.5	32		16	300	
New York	Grand Central	79.0	67	33.6	36	615	60,000
	Pennsylvania	28.0	21	16.0	11	334	47,000
St. Louis	Union	10.9	32	5.4	16	315	
Washington	Union	13.0	29		13	222	
EUROPE							
Cologne	Main	5.8	14	3.4	9		
Dresden	"	7.0	14	3.0	8		
Frankfort	"	11.0	18		9	625	
London	L. B. & So. Coast	14.0					
	L. & So. W'n	16.04	18		12	966	80,000
	Gt. Eastern	8.0	18		11	1400	200,000 max.
Manchester	Lancashire & Yorkshire	13.5			17	736	
Paris	St. Lazare	27.0	31	3.5	14	1200	250,000 max. 83,000 av.

XXVI. Pennsylvania Railroad Station, New York City

First stone laid, June 15, 1908.
Opened for general traffic, November 27, 1910.

AREA

The area from Tenth Avenue to the normal section of the tunnel east of Seventh Avenue is 28 acres.

The excavation amounted to about 3,000,000 cubic yards, mostly rock.

The retaining walls are 1½ miles in total length and, with the foundations and substructures, contain 160,000 cubic yards of concrete.

TRACKS

There are 16 miles of tracks within the terminal area and, within the building, 21 standing tracks with 11 platforms of a total length of 21,500 feet.

STATION-BUILDING

The station-building fronts 430 feet on Seventh and Eighth Avenues and covers the two blocks between Thirty-first and Thirty-third streets, with the intervening street, for 788 feet, at an average height above the street level of 69 feet and a maximum height of 153 feet. The exterior walls aggregate 2458 feet in length and contain 490,000 cubic feet of pink granite; the interior walls contain 60,000 cubic feet of a different kind. There were used in addition 15,000,000 brick and 27,000 tons of steel.

The building has entrances from the streets on its four sides. The main entrance on Seventh Avenue, for foot passengers only, is through a portico 102 feet in length with a double row of Roman Doric columns, each 35 feet high and 4 feet 10 inches in diameter. The entablature is surmounted by a stepped parapet and a sculptured group supporting a clock dial, 7 feet in diameter and 61 feet above the sidewalk. On each side of the portico is a colonnade of eight columns of 101 feet front, back of which is a row of shops 40 feet deep, opening on to the interior court. Beyond these colonnades, at the corners of the Seventh Avenue front, are entrances through porticoes with double columns and pediments to carriageways 61 feet wide, descending to the level of the waiting-rooms, the concourse and the baggage-room. The side entrances to the station span these carriageways over wide bridges.

The main entrance on Seventh Avenue opens into a vestibule 44 feet by 70 feet and 66 feet to the vaulted ceiling. On each side are corridors with stairways and elevators to the floors above. An arch at the farther end of the vestibule opens into an arcade 225 feet long by 45 feet wide, leading to the general waiting-room. On each side of this arcade are shops, restaurants and lunch-rooms.

The general waiting-room extends across the building from Thirty-first Street to Thirty-third Street for 314 feet. It is 108 feet wide and 150 feet to the pitch of the ceiling. In each of the cross-walls, which rise above the roofs of the other parts of the building, are three semi-circular windows of 33 feet radius, each beneath a gable; and there is a similar window at each end of the room. Within this room are the ticket offices, a baggage-checking office, parcel-rooms, telegraph-offices and telephone-booths. Adjoining this room, on one side, are a women's waiting-room and a smoking-room, each 58 feet by 100 feet. On the other side is the main baggage-room, 276 feet by 114 feet, with a frontage of 450 feet for transfer-wagons. This room is connected with a subway 30 feet wide, extending under and along Thirty-first Street, Seventh and Eighth Avenues, by which delivery is made to the tracks by motor-trucks and elevators.

Parallel to the general waiting-room, and connected with it by a wide thoroughfare between the subsidiary waiting-rooms, is the concourse, a covered assembling place extending across the station. The concourse and adjoining areas open on to the tracks and form a courtyard 340 feet by 210 feet, roofed by a lofty train-shed of iron and glass. Auxiliary to the main concourse, and between it and the track-platforms, is a sub-concourse 60 feet wide, 18 feet above the track-level and connected with it by two stairways and an elevator at each platform. From this sub-concourse there are ample exits by stairways and ramps to the cab-stands, to the side-street entrances and to Eighth Avenue. The side of the station along Thirty-third Street is assigned to the train-service of the Long Island Railway.

The principal entrances are illuminated by electric lights grouped on posts, the colonnade by suspended lamps and the central vestibule by clusters on eight bronze standards. There are 30,000 incandescent and arc lights in the station-building.

XXVII. New York Central Railroad, Grand Central Station, New York City

Work of reconstruction commenced July, 1903.
Opened for general traffic February 2, 1913.

AREA

The terminal station and yards cover seventeen city-blocks, extending from Forty-second street to Fifty-ninth street; the yard proper, which is located south of Fiftieth street extends from Madison Avenue to Lexington Avenue. In this area there are spaces on two levels; 46.4 acres on the upper or express level and 32.8 acres on the lower or suburban level. The area of the old terminal was 23.24 acres with a car-capacity of 366 cars. The new terminal has a capacity of 1131 cars.

The excavation amounted to 3,094,751 cubic yards. The materials of construction include 352,051 cubic yards of concrete; to carry tracks, viaducts, and for buildings which have been erected and proposed buildings, 188,000 tons of steel and 6885 columns.

TRACKS

There are 32.82 miles of track in the terminal area, 18.71 miles on the upper level and 14.11 miles on the lower level. There are 50 platform-tracks. Against 18 platforms on the upper level there are 33 tracks, measuring 28,850 feet and 17 tracks against 14 platforms on the lower level, measuring 13,000 feet; a total of 41,850 feet, or 7.93 miles. The platforms are from 14 feet to 33 feet in width.

STATION-BUILDING

The station-building has a frontage of 302 feet on Forty-second Street and of 672 feet on Vanderbilt Avenue. It is in the Renaissance style, the exterior being of limestone and granite. Below the street level it is 745 feet in length by 450 feet in width. There are five levels; a mezzanine floor or gallery on the street level surrounding the concourse for express trains on a level about 18 feet below; beneath this level is the concourse for suburban trains, from which lead ramps to the suburban platforms about 13 feet below the suburban concourse; underneath the suburban tracks are cross-subways for the transfer of mail, baggage and express.

On approximately the same level with the express-train platforms are a concourse for incoming passengers, which will accommodate 2500 persons, and the main concourse for departing trains, which will accommodate 13,000 persons. This outbound concourse is 275 feet long by 120 feet wide, and is 125 feet in height to the barrel vault ceiling with 33,000 square feet of floor space. Around it are ranged in a length of about 320 feet 28 windows to railroad-ticket and Pullman-ticket offices, baggage-checking, parcel-room and telegraph counters. The information bureau is located in the center of the concourse. Upon the ceiling are depicted 2500 stars in the constellations of a section of the Zodiac as seen in that latitude between October and March with 63 of the brighter stars indicated by electric lamps. The concourse is finished in Botticino marble and buff-tinted stone, and is lighted through 6 large windows in the ends. The adjacent waiting-rooms have 18,500 square feet of floor space, will hold about 7000 persons, with seating-capacity for about 650, and are flanked by restaurants and shops. The lower or suburban concourse is of about the same dimensions and with a similar arrangement of ticket-offices, parcel-rooms, etc. Both concourses are connected by passageways with the Grand Central Subway Station. There are separate accommodations for immigrants.

The baggage-room in the old station handled 5000 to 6000 pieces a day. The room in the new station has handled 11,000 pieces. There are storerooms where 300 trainmen obtain their equipment of lamps, flags, etc., when going on duty. On one of the upper floors in the building are rest rooms for trainmen in which are located clothes-lockers and lavatories.

SUBURBAN LOOPS

Eight of the inbound suburban-level tracks will finally be connected into loops at the south end, allowing trains to be turned and placed on outbound tracks. Three of these loop connections are now in service.

(Information furnished by George A. Harwood, Engineer in charge of Terminal.)

XXVIII. Recently Constructed Passenger Terminal Stations

CHICAGO

Chicago & North Western Railway Company.

Begun February, 1909; opened June 4, 1911. Second largest station in the world to be occupied by a single company. Total area, 20 acres.

Total cost, $23,750,000; including $11,560,000 for real estate.

Train-shed, 894 feet long; 265,000 square feet in area; 16 tracks under the train-shed, each with capacity for 15 cars.

Station-building, 320 feet by 218 feet; granite with colonnade-portico rising 140 feet above the street, with six public entrances. Concourse, 320 feet by 60 feet. General waiting-room, 202 feet by 117 feet.

Union Station. Proposed reconstruction to replace building erected in 1880; to be occupied by Pennsylvania Lines, Chicago & Alton Railroad, Chicago, Burlington & Quincy Railroad, and Chicago, Milwaukee & St. Paul Railroad.

Terminal to cover 35 acres in the heart of the business section valued at	$32,000,000
Street changes, viaducts and property damages at	4,500,000
Station improvements at	10,500,000
Total	$47,000,000

Dead-end tracks for trains departing in opposite directions, with concourse between. Six approach-tracks at each end of the concourse with crossovers. Two through tracks on one side of the terminal. Station-tracks in pairs, 13 feet between centers. Platforms between pairs. Thirteen tracks in the south yard, 545 feet to 1395 feet in length, and nine in the north yard, 815 feet to 1405 feet in length.

Concourse, 380 feet by 180 feet. Waiting-room, 250 feet by 100 feet.

JERSEY CITY

Central Railroad of New Jersey.

Ferry Terminal. Opened April, 1914.

Train-shed, 818 feet by 370 feet, covering 18 tracks with "Bush" sheds. Built of reinforced concrete in nine connected vaults and a cantilever-extension on each side, supported by iron columns 18 feet high on center line of concrete platforms, of which 4 are 16 feet wide, 4 are 18 feet wide and 2 are 20 feet wide.

Train-concourse, 383 feet by 63 feet.

Ferry-concourse, lower story, 348 feet by 75 feet, upper story, 302 feet by 50 feet; to provide for direct communication between upper deck of ferry-boats and trains by escalators and ramps.

Four double-decked steel buildings adjoining the ferry-slips to accommodate the baggage-room, mail-room, local ferry waiting-room and stationary department.

Locomotive-terminal with two roundhouses with total of 66 stalls, a 1600-ton coaling plant, a machine shop and other facilities.

Total length of terminal property, nearly one mile.

KANSAS CITY

Kansas City Terminal Railway.

Union Station to accommodate 27 lines of 14 railroad systems with 300 trains daily; including freight-terminal. Total cost of $40,000,000.

Station-building to cost $11,000,000; four stories front and five stories in rear, Train-shed, 410 feet by 165 feet. Sixteen through tracks in pairs, each 2800 feet long.

Platforms covered by umbrella sheds, 1370 feet long, and ten stub tracks.

Main building, 515 feet by 50 feet. Concourse, 103 feet by 242 feet with vaulted glass roof, 92 feet above the floor. Main waiting-room, 352 feet by 78 feet, extending over the platforms and connected with rear building containing a waiting-room for immigrants.

"Midway" on each side of the main waiting-room, one for inbound and the other for outbound passengers, with stairways and escalators to the platforms. Floors beneath occupied by baggage-room, mail-room and express-room; all connected with the train platforms by subways.

WASHINGTON, D.C.

Union Station, used by seven railroad companies. Opened in 1907

Area, 100 acres, in three sections; North Approach, Terminal Station and South Approach. Plaza facing station-building, 500 feet by 100 feet, from which radiate nine streets. Filling within the grounds, 900,000 cubic yards. 1,000,000 cubic yards required to raise the plaza and adjacent streets, and 2,500,000 cubic yards for the area occupied by the yards for cars, locomotives and repairs.

North Approach is over an eight-track viaduct into a train-yard of 35 tracks, with a power-plant and express-building, a yard for storing 750 cars, a locomotive yard and a car-repair yard.

South Approach includes the girder-covered work under the plaza and a double-track tunnel under Capitol Hill.

The station-building is 663 feet by 211 feet, and from 65 feet to 150 feet in height, of marble and white granite, with a portico on the front and sides. Tracks on two levels. Basement-level, 16 feet below the concourse-level, reached by inclined driveways on each side of the building; 20 stub tracks on concourse level, 8 through tracks on basement-level and 3 storage-tracks on the side of the station-building for baggage and mail cars.

Platforms 915 feet long and 21 feet wide, each serving two tracks; 13 on concourse level with umbrella sheds, 5 on basement level with elevators to baggage-rooms.

Main waiting-room, 220 feet by 130 feet. Barrel-vaulted roof, 93 feet high. Concourse, 760 feet by 130 feet, said to be the largest room with a single floor in the world.
Special entrance for the President of the United States.
Executive offices in the upper stories.

XXIX. Great Salt Lake Cut-off

An example of relocation on an extensive scale, by which many miles of heavy grades and curvature were avoided, and which is as remarkable for rapidity of construction as for its economic efficiency.

Beginning at Umbria Junction, near Lucin, on the Central Pacific line, and 4517 feet above sea-level. the new line is 103.8 miles in length to Cecil Junction, near Ogden, the western terminus of the Union Pacific Railroad, and 4298 feet above sea-level. It is virtually an air-line, almost 104 miles in length, for the most part at a general level of 4217 feet above sea-level, with three slight breaks of grade of 4 per cent., or of 21.12 feet per mile. The location is directly across two arms of Great Salt Lake, 31.6 miles from shore to shore, with an intervening stretch of 3½ miles of earthwork at Promontory Point. In this distance of 31.6 miles, there are also some 4 miles of embankment and 23 miles of trestling, of which 11 miles were afterward filled in.

The permanent trestling is built in bents of five piles and 15 feet span, supporting a floor 16 feet out to out, made up of 3 by 12-inch plank upon twelve 8 by 17-inch stringers. Floor asphalted and covered with 15 inches of ballast. Hand rails on each side, 3 feet 7 inches above level of ties. Track-level about 19 feet above the ordinary surface of the lake, which has a maximum depth of about 36 feet. 38,256 piles were used in its construction, ranging to 70 and 110 feet in length; approximately equivalent to 535 linear miles of piling.

The construction of the line was commenced in July, 1902, and completed in November, 1903. A force of three thousand men was employed upon the work, which was prosecuted at night by electric light. Steam-shovels were used with buckets of about six yards' capacity, with a maximum movement of about 400 carloads of filling per day. The same energy characterized the bridge-construction, in which 1140 linear feet of trestling per day were completed for five days in succession. 1680 tons of fresh water were consumed daily, hauled by trains from distances of 80 to 130 miles.

The original line, around the northern shore of Great Salt Lake, was 147.57 miles between the same junction points, with four intervening elevations rising from an altitude of 4223 feet, respectively to 4720, 4714, 4723 and 4907 feet, with gradients of 1.25 to 1.7 per cent., or of 66 to 90 feet to the mile.

COMPARISON BETWEEN THE ORIGINAL LINE AND THE CUT-OFF

	Old Line	*Cut-off*	*Difference*
Distance, miles	147.576	103.804	43.772
Lowest intermediate altitude, feet	4,223.	4,217.	6.
Highest intermediate altitude, feet	4,907.	4,253.	644.
Heaviest gradient, per cent.	1.7	0.4	1.3

Elimination of 1515 feet vertical of grade and of 3919 degrees of curvature, with five hours saving in time of passenger train schedules.

Construction in charge of William Hood, Chief Engineer, Southern Pacific Company.

(Information furnished by John D. Isaacs, Consulting Engineer, Southern Pacific Company.)

XXX. Delaware, Lackawanna & Western Railroad

HOPATCONG CUT-OFF

From Port Morris, N. J., to Slateford, Pa., 28.5 miles.

An alternative line to that via Washington, N. J., shortening the intermediate distance by 11.1 miles. Opened for traffic, December 26, 1911. Cost, $11,500,000. Double track; no grade-crossing of either railroad or highway. Maximum gradient, 29 feet per mile. Maximum curvature, 2 degrees, with one exception of 3½ degrees. Concrete viaduct across Delaware River, 1452 feet in length, with five arches of 150 feet span and two of 120 feet span. Concrete viaduct over Paulin's Kill, 1100 feet in length and 115 feet above water-level. Pequest Fill, 3 miles in length, average height 75 feet, contains 6,625,000 cubic yards of material. Armstrong cut, over a mile in length, maximum depth, 104 feet; average depth, 50 feet. Colby cut, ½ mile in length, maximum depth, 110 feet; average depth, 45 feet; 462,000 cubic yards of excavation through solid granite. Total excavation, 7,890,000 cubic yards of earth and 6,502,000 cubic yards of rock, 5,700,000 cubic yards of borrowed material in embankments.

RECONSTRUCTION BETWEEN CLARK'S SUMMIT AND HALLSTEAD, PA.

Distance, 37 miles. Cost, $12,500,000. Opened for traffic, November 6, 1915. Saving in distance of 3.6 miles, of 2400 degrees of curvature and reduction in gradients from 1.23 per cent. to 0.68 per cent., or from 65 feet to the mile to 36 feet to the mile.

Tunkhannock Viaduct. 2,375 feet in length; 240 feet above surface of stream. Ten spans of 180 feet and two of 100 feet; contains 4,500,000 cubic feet of concrete and 2,280,000 pounds of reinforcing steel.

Martin's Creek Viaduct. 1600 feet in length; 150 feet above bed of creek; contains 2,092,500 cubic feet of concrete and 1,600,000 pounds of reinforcing steel.

Double-track tunnel, 3600 feet in length.

Cut at Clark's Summit, 2 miles in length, from 20 feet to 60 feet in depth.

Fill near Dalton, 115 feet in height; and one near Tunkhannock Creek, 2000 feet in length, 140 feet high, containing 1,600,000 cubic yards of material.

Twenty-two level crossings eliminated.

XXXI. Erie Railroad

FEATURES OF RECONSTRUCTION. 1901 TO 1914

Reduction in Ruling Gradients.

Between Jersey City and Salamanca, 414 miles. Eastbound, from 0.65 per cent. to 0.2 per cent.

Between Marion, O., and Hammond, Ind., 249 miles. Eastbound, from 0.5 per cent. to 0.2 per cent. and 0.3 per cent. Westbound, from 0.55 per cent. to 0.2 per cent. Ninety-five per cent. of this part of the line is on a tangent.

Between Jersey City and Chicago, rise and fall reduced from 7886 feet to 6512 feet, or 18 per cent.

Track. Second-track mileage, on 2359 miles of track, increased from 701 miles to 1213 miles; third and fourth tracks, from 24 miles to 45 miles.

There are now but 51 miles of single track between Jersey City and Chicago, 998 miles.

Average weight of rail increased from 83 pounds to 91 pounds per yard.

Bridges. 841 new bridges on main line.

Automatic Block Signals. None in 1901. In 1914, 1452 miles so equipped.

Additions and Betterments. Cost about $100,000,000, of which $13,413,000 was paid out of income.

APPENDIX VI

Accidents, Traffic Statistics

Notes and Tables I to XX

I. Casualties to Employees — United States

Cause	1913		1914	
	Killed	Wounded	Killed	Wounded
On Duty				
In collisions	302	3,935	231	2,660
In derailments	244	2,806	217	2,391
In other train accidents	51	1,311	18	780
In coupling accidents	195	3,360	171	2,692
Overhead obstruction	96	1,844	90	1,498
Falling from cars, etc.	575	16,157	513	14,740
Total	1,463	29,413	1,240	24,761
Off Duty				
Train accidents	12	146	5	117
Coupling accidents		1		2
Overhead obstruction	2	9	3	5
Falling from cars, etc.	65	408	54	370
Total	79	564	62	494
All employees	1,542	29,977	1,302	25,255

Bureau of Railway News and Statistics.

II. Automatic Train Control

Requisites of Installation — American Railway Association

Approved May 20, 1914

An installation so arranged that its operation will automatically result in either one or the other or both of the following conditions:

First. — The application of the brakes until the train has been brought to a stop.

Second. — The application of the brakes when the speed of the train exceeds a prescribed rate and continued until the speed has been reduced to a predetermined rate.

REQUISITES OF INSTALLATION

Note. — These requisites are drawn for application in connection with a properly installed block signal or interlocking system.

1. The apparatus so constructed that the failure of any essential part will cause the application of the brakes.

2. The apparatus so constructed that it will automatically control the train in the event of failure by engineman to observe signals or speed regulations.

3. The apparatus so constructed that it will control the train in the event of a failure of fixed signals to give proper indications.

4. The apparatus so constructed that proper operative relation between those parts along the roadway and those on the train will be assured under all conditions of speed, weather, wear, oscillation and shock.

5. The train apparatus so constructed as to prevent the release of the brakes after automatic application has been made until the train has been brought to a stop or the speed of the train has been reduced to a predetermined rate.

6. The train apparatus so constructed that when operated it will make an application of the brakes sufficient to stop or control the train within a predetermined distance.

7. The apparatus so constructed as not to interfere with the application of the brakes by the engineman's brake valve or the efficiency of the air-brake system.

8. The apparatus so constructed as to be operative when the engine is running forward or backward.

9. The apparatus so constructed that when two or more engines are coupled together or a pusher is being used the apparatus can be made effective on the engine only from which the brakes are controlled.

10. The apparatus so constructed as to be operative on trains moving only with the current of traffic.

11. The apparatus so constructed as to conform to The American Railway Association standard of clearances of rolling equipment and structures.

12. The apparatus so constructed as not to constitute a source of danger to employees or passengers, either in its installation or operation.

13. The apparatus so constructed as not to interfere with the means used for operating fixed signals.

ADJUNCTS

The following may be used:

(A) Cab Signal; a signal located in the engine cab indicating a condition affecting the movement of the train and so constructed that the failure of any part directly controlling the signal will cause it to give the "stop" indication.

(B) Detonating Signal Apparatus; an apparatus located along the roadway and so constructed as to give an audible signal by means of a torpedo or other explosive cartridge.

(C) Speed Indicator.

(D) Recording Device; an apparatus located on the train and so constructed as to make a record of the operations of the automatic applications of the brakes and of the speeds of the train, and such other records as may be desirable.

III. Train Accidents in the United States from Defects of Equipment and Roadway

(Compiled from Report of Interstate Commerce Commission)

Defects	For Year Ending June 30, 1916	Average — 1907 to 1916, Inclusive
	Number	Number
Wheels	999	1,065
Axles	490	392
Brake Rigging	472	439
Draft Gear	319	235
Trucks	665	443
Brake Apparatus	442	229
Couplers	215	180
Miscellaneous	471	395
Defects of Equipment	4,073	3,378
Bad Track	1,098	844
Broken Rails	272	279
Miscellaneous	303	393
Defects of Roadway	1,673	1,516
Grand Total	5,746	4,894

IV. Railway Grade Crossings, 1915

Compiled from Statistics of Railways, United States Bureau of Railway Economics

Kind of Crossing	Protected		Total Protected	Unprotected	Total
	By Gates, Flagmen or Interlocking	By Crossing Alarm			
EASTERN DISTRICT					
Steam Railway	2,696	31	2,727	529	3,256
Electric "	1,378	52	1,430	763	2,193
Street and Highway	9,226	3,553	12,779	55,462	68,241
Total	13,300	3,636	16,936	56,754	73,690
SOUTHERN DISTRICT					
Steam Railway	691	12	703	978	1,681
Electric "	312	5	317	347	664
Street and Highway	1,279	439	1,718	47,389	49,107
Total	2,282	456	2,738	48,714	51,452

IV. RAILWAY GRADE CROSSINGS, 1915 — *Continued*

Kind of Crossing	Protected: By Gates, Flagmen or Interlocking	Protected: By Crossing Alarm	Total Protected	Unprotected	Total
WESTERN DISTRICT					
Steam Railway	2,516	9	2,525	2,657	5,182
Electric "	801	31	832	1,105	1,937
Street and Highway . .	5,537	3,034	8,571	114,774	123,345
Total	8,854	3,074	11,928	118,536	130,464
UNITED STATES					
Steam Railway	5,903	52	5,955	4,164	10,119
Electric "	2,491	88	2,579	2,215	4,794
Street and Highway . .	16,042	7,026	23,068	217,625	240,693
Total	24,436	7,166	31,602	224,004	255,606

RAILWAY CROSSINGS UNPROTECTED

	Eastern Dist.	Southern Dist.	Western Dist.	United States
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Steam Railway	16	58	51	40
Electric "	35	52	57	46
Street and Highway	52	97	93	91

GRADE CROSSINGS ELIMINATED

	Eastern Dist.	Southern Dist.	Western Dist.	United States
Steam Railway	12	10	22	44
Electric "	8	3	6	17
Street and Highway	137	124	205	466
Total	157	137	233	527

V. Fast Train Service for Distances of 400 Miles and Over, Including Intermediate Stops

UNITED STATES

Winter Time-Tables — 1916-1917

From	To	Distance Miles	Time Hours	Miles per Hour
New York	Buffalo	441	9.0	49.0
" "	Chicago	870	20.0	43.5
" "	"	960	20.0	48.0
Washington	Jacksonville, Fla.	755	18.5	40.8
"	"	792	17.9	44.2
Chicago	Minneapolis	424	11.75	36.1
"	"	442	12.41	35.6
"	New Orleans	930	23.0	40.4
"	Seattle	1,828	67.75	27.0
"	"	1,911	66.5	28.8
"	San Francisco	2,276	61.17	37.2
New Orleans	" "	2,487	86.5	28.8

CANADA — 1916-1917

Montreal	Vancouver	2,898	109.16	26.6

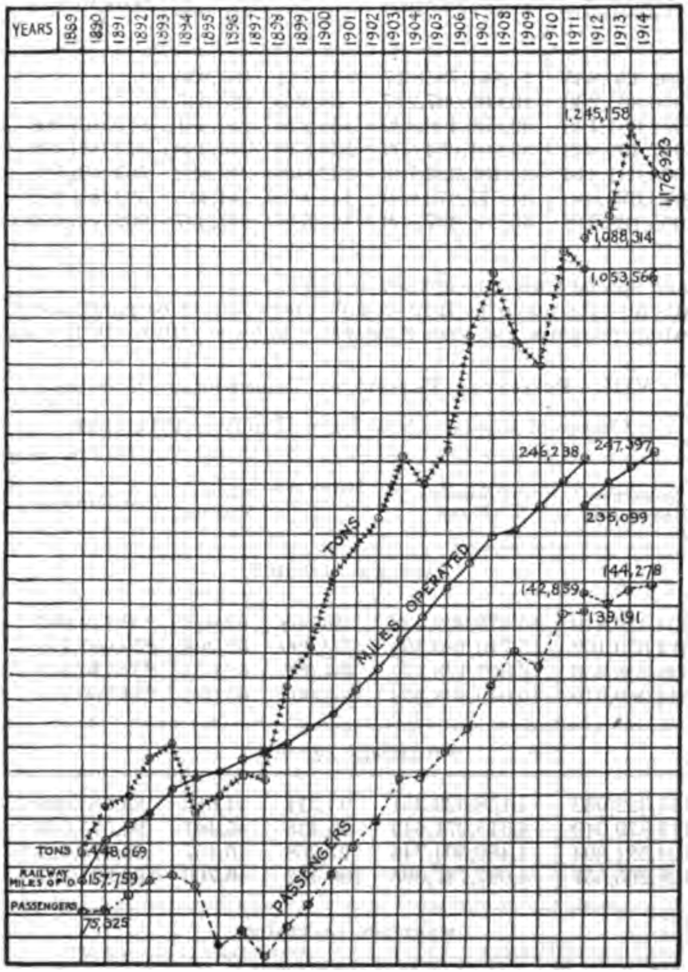
EUROPE (Railway Age Gazette, July 8, 1910)

London	Glasgow	402	8.0	50.2
"	"	424	8.75	48.5
"	Aberdeen	523	11.12	47.0
"	"	540	11.25	48.0
Paris	Bayonne	486	9.53	51.0
"	Nice	676	13.83	48.9
Berlin	"	1,155	26.25 [1]	44.0

[1] Custom-house stops included.

VI. Relative Density of Railway Traffic in the United States per Mile of Line, 1889–1914

Minor Lines omitted after 1912. New Base of Line Mileage after 1911



VII. Passenger Traffic — United States

Compiled from Reports of Interstate Commerce Commission

Year	Number of Passengers	Passenger Miles	Miles per Mile of Line	Railway Mileage	Train Mileage	Passenger per Train-mile
1890	402,430,865	11,847,785,617	75,751	165,936		
1900	576,865,230	16,039,007,217	83,295	193,345		
1910	971,683,199	32,338,496,329	134,279	240,831	549,015,008	58.9
1911	997,409,882	33,201,694,699	134,836	246,238	572,929,421	57.9
1912	1,004,081,346	33,132,354,783	132,608	249,852	585,853,528	56.5
1913	1,033,679,680	34,575,872,980	141,462	244,418	593,061,212	58.3
1914	1,055,138,718	35,258,497,509	142,516	247,397	602,383,660	58.5

Mixed and special train-mileage not included.

The statistics subsequent to 1912 exclude operations of corporations (Class III) with operating revenues less than $100,000. Mileage (1914), 10,106 miles.

VIII. Passenger Traffic by Territorial Districts

Classes of Roads — Nos. I and II only — 1911–1914

Year	Number of Passengers	Passenger Miles	Miles per Mile of Line	Railway Mileage	Train Mileage	Passengers per Train-mile
			EASTERN DISTRICT			
1911	604,419,819	15,478,962,423	249,568	62,023	250,529,995	61.7
1912	614,670,102	15,710,180,498	252,299	62,268	250,607,791	62.4
1913	636,238,459	16,397,128,722	261,625	62,674	252,790,510	64.8
1914	640,389,619	16,649,408,363	263,904	63,088	254,769,268	65.3
			SOUTHERN DISTRICT			
1911	116,322,932	4,158,623,351	93,211	44,615	85,563,605	48.6
1912	119,879,040	4,315,071,645	95,435	45,401	90,575,666	47.6
1913	124,581,894	4,489,604,748	97,268	46,157	93,175,424	48.1
1914	128,265,557	4,697,747,095	100,452	46,766	96,931,357	48.4
			WESTERN DISTRICT			
1911	266,968,246	13,470,875,368	104,053	129,461	234,022,478	57.5
1912	259,823,141	13,013,858,665	98,796	132,737	241,569,069	53.8
1913	272,859,427	13,689,139,570	100,954	135,587	247,095,278	55.4
1914	284,483,542	13,911,342,051	101,141	137,543	250,488,035	55.5
			UNITED STATES			
1911	987,710,997	33,108,461,142	140,231	236,099	570,116,038	58.5
1912	994,372,283	33,039,110,808	137,430	240,406	582,752,526	56.7
1913	1,033,679,680	34,575,872,980	141,462	244,418	593,061,212	58.3
1914	1,053,138,718	35,258,497,509	142,516	247,397	602,383,660	58.5

IX. Average Length of Journey in Miles, in 1911 and in 1914

District	1911		1914	
	Class I	Class II	Class I	Class II
Eastern	26.45	12.09	26.86	10.91
Southern	36.39	19.70	37.62	17.77
Western	51.82	24.78	50.15	21.94
United States	34.49	16.72	34.49	14.85

X. Proportionate Distribution of Passenger Traffic — 1914

District	Number of Passengers	Passenger Miles	Railway Mileage	Train Mileage
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Eastern	60.9	47.2	25.5	42.3
Southern	12.1	13.3	18.9	16.0
Western	27.0	39.5	55.6	41.7

XI. Annual Rate of Increase. Passenger Traffic

Year	No. of Passengers	Passenger Miles	Per Mile of Line	Train Mileage
1890				
1900	8,443,436	419,132,160	754	
1910	39,481,796	1,629,948,911	5,298	
1911	25,726,683	86,319,837	597	23,914,418
1912	6,671,464	69,339,916 [1]	2,228 [1]	12,924,107
1913	29,598,334	1,413,518,197	8,854	7,217,684
1914	19,359,038	682,624,529	1,054	9,327,448

XII. Freight Traffic — United States

Compiled from Reports of Interstate Commerce Commission

Year	Tons	Ton-miles	Per Mile of Line	Train Mileage	Average Train-Load	Average Haul
					Tons	Miles
1890	636,541,617	76,207,047,298	487,245			119
1900	1,081,983,301	141,596,551,161	735,352			138
1910	1,745,324,828	255,016,910,451	1,071,086	635,950,681	401	146
1911	1,781,638,043	253,783,701,839	1,053,566	626,496,025	405	142
1912	1,844,977,673	264,080,745,058	1,078,580	612,345,112	431	143
1913	2,058,035,487	301,398,752,108	1,245,158	643,841,292	466	146
1914	1,976,138,155	288,319,890,210	1,176,923	605,923,249	475	146

1913–14 Tonnage of minor lines excluded = 300,836,804 tons in 1912.

(*Continued on next page*)

XII. Freight Traffic — United States — *Continued*

Year	Tons	Ton-miles	Per Mile of Line	Train Mileage	Average Train-Load	Average Haul
ANNUAL RATE OF INCREASE						
					Tons	Miles
1890						
1900	44,744,168	6,538,950,386	24,810			
1910	66,334,152	11,342,035,920	33,573			
1911	36,313,215	1,232,208,612[1]	11,520[1]	8,954,656[1]	4	
1912	63,339,630	10,297,043,214	25,014	14,150,913[1]	26	
1913	213,051,814	37,318,007,050	166,578	31,496,180	35	
1914	81,897,332[1]	13,078,861,898[1]	68,235[1]	37,918,043[1]	9	

[1] Decrease.

XIII. Tonnage Statistics by Territorial Districts

Classes of Roads I and II only — 1911–14

Year	Tons	Ton-Miles	Per Mile of Line	Train Mileage	Tons per Train-mile
EASTERN DISTRICT					
1911	1,059,065,209	130,740,368,357	2,107,933	278,581,012	469
1912	1,098,773,108	134,856,670,210	2,165,746	270,979,016	497
1913	1,292,445,213	154,172,856,257	2,459,417	284,010,552	542
1914	1,173,127,839	144,427,881,290	2,289,308	262,648,387	549
SOUTHERN DISTRICT					
1911	230,708,929	41,656,924,908	933,698	115,529,577	365
1912	230,941,625	44,172,334,878	972,937	115,988,370	388
1913	263,847,819	48,543,394,380	1,051,741	119,540,732	406
1914	273,213,156	50,131,636,290	1,071,967	119,779,293	418
WESTERN DISTRICT					
1911	463,415,801	81,059,095,872	626,124	230,233,787	352
1912	479,180,897	84,648,903,166	637,719	222,324,443	387
1913	551,742,455	98,682,501,471	727,074	240,290,008	410
1914	529,797,160	93,760,372,630	681,680	223,495,569	419
UNITED STATES					
1911	1,753,189,939	253,456,389,137	1,073,517	624,344,376	405
1912	1,808,895,630	263,677,908,254	1,096,802	609,311,829	432
1913	2,058,035,487	301,398,752,108	1,233,128	643,841,292	468
1914	1,976,138,155	288,319,890,210	1,165,644	605,923,249	442

XIII. Tonnage Statistics by Territorial Districts — *Continued*

Average Haul in Miles in 1911 and 1914

District	1911		1914	
	Class I	Class II	Class I	Class II
Eastern	134	23	129	19
Southern	187	34	193	35
Western	191	32	191	30

Proportionate Distribution of Freight Traffic, 1914

District	Tons	Ton-miles	Railway Mileage	Train Mileage
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Eastern	59.4	50.1	25.5	43.3
Southern	13.8	17.4	18.9	19.8
Western	26.8	32.5	55.6	36.9

XIV. Freight Traffic from Points of Origin — 1912–1914

Roads, Class I and Class II, in 1913 and 1914
Roads, Class III, included in 1912 — Total tonnage, 18,911,922 tons

Products or Commodities	1912 Tons	Per Cent. of Total	1913 Tons	Per Cent. of Total	1914 Tons	Per Cent. of Total
EASTERN DISTRICT						
Agriculture	26,041,392	5.09	26,973,005	4.67	24,295,110	4.55
Animals	8,894,392	1.74	8,926,737	1.54	9,329,572	1.75
Mines	315,581,446	61.64	359,230,979	62.11	338,192,206	63.40
Forests	22,964,432	4.48	23,431,387	4.05	21,733,390	4.07
Manufactures	93,951,237	18.35	110,483,255	19.10	96,876,283	18.16
Merchandise	16,689,086	3.26	17,951,771	3.10	15,932,247	2.99
Miscellaneous	27,848,624	5.44	31,385,652	5.43	27,073,603	5.08
Total	511,970,609	51.3	578,382,786	50.5	533,432,411	48.8
SOUTHERN DISTRICT						
Agriculture	14,918,163	8.68	14,114,467	7.90	14,808,528	8.00
Animals	2,314,127	1.35	2,598,745	1.46	3,161,890	1.71
Mines	97,535,577	56.80	101,003,003	56.52	106,978,918	57.77
Forests	28,329,316	16.50	30,789,088	17.23	30,133,630	16.27
Manufactures	18,646,669	10.86	19,641,814	10.99	19,200,365	10.37
Merchandise	6,938,705	4.04	7,312,038	4.09	7,656,244	4.13
Miscellaneous	3,034,836	1.77	3,229,235	1.81	3,236,165	1.75
Total	171,717,393	17.2	178,688,390	15.7	185,175,740	16.9

XIV. Freight Traffic from Points of Origin — 1912–1914 — *Continued*

Products or Commodities	1912 Tons	Per Cent. of Total	1913 Tons	Per Cent. of Total	1914 Tons	Per Cent. of Total
WESTERN DISTRICT						
Agriculture	49,816,934	15.84	64,979,845	16.76	63,096,269	16.80
Animals	13,765,652	4.38	14,920,900	3.85	14,647,172	3.90
Mines	153,421,364	48.77	190,706,271	49.18	180,904,542	48.18
Forests	48,853,723	15.53	57,858,689	14.92	59,010,761	15.71
Manufactures	27,350,747	8.69	35,406,966	9.13	33,106,633	8.82
Merchandise	14,701,676	4.67	17,256,560	4.45	17,885,747	4.76
Miscellaneous	6,684,427	2.12	6,639,896	1.71	6,884,620	1.83
Total	314,594,523	31.5	387,769,127	33.8	375,515,744	34.3
UNITED STATES						
Agriculture	90,776,489	9.09	146,067,317	9.27	102,199,907	9.34
Animals	24,974,171	2.50	26,446,382	2.31	27,138,634	2.48
Mines	566,538,387	56.75	650,940,253	56.86	626,075,666	57.22
Forests	100,147,471	10.03	112,079,164	9.79	110,877,781	10.13
Manufactures	139,948,653	14.02	165,532,035	14.46	149,183,281	13.64
Merchandise	38,329,467	3.84	42,520,369	3.71	41,974,238	3.79
Miscellaneous	37,567,887	3.77	41,254,783	3.60	37,174,388	3.40
Total	998,282,525		1,144,840,303		1,094,123,895	

Average percentage — Commodity tonnage — 1912–14

Commodities	Eastern District	Southern District	Western District	United States
Agriculture	4.8 per cent.	8.2 per cent.	16.5 per cent.	9.2 per cent.
Animals	1.7 per cent.	1.5 per cent.	4.0 per cent.	2.4 per cent.
Mines	62.4 per cent.	57.0 per cent.	48.7 per cent.	57.0 per cent.
Forests	4.2 per cent.	16.7 per cent.	15.4 per cent.	10.0 per cent.
Manufactures	18.5 per cent.	10.7 per cent.	8.9 per cent.	14.0 per cent.
Merchandise	3.1 per cent.	4.1 per cent.	4.6 per cent.	3.8 per cent.
Miscellaneous	5.3 per cent.	1.8 per cent.	1.9 per cent.	3.6 per cent.
Total	50.2 per cent.	16.5 per cent.	33.3 per cent.	100 per cent.

XV. LOSS AND DAMAGE CLAIMS PAID BY RAILROADS IN UNITED STATES FROM JAN. 1 TO SEPT. 30, 1914

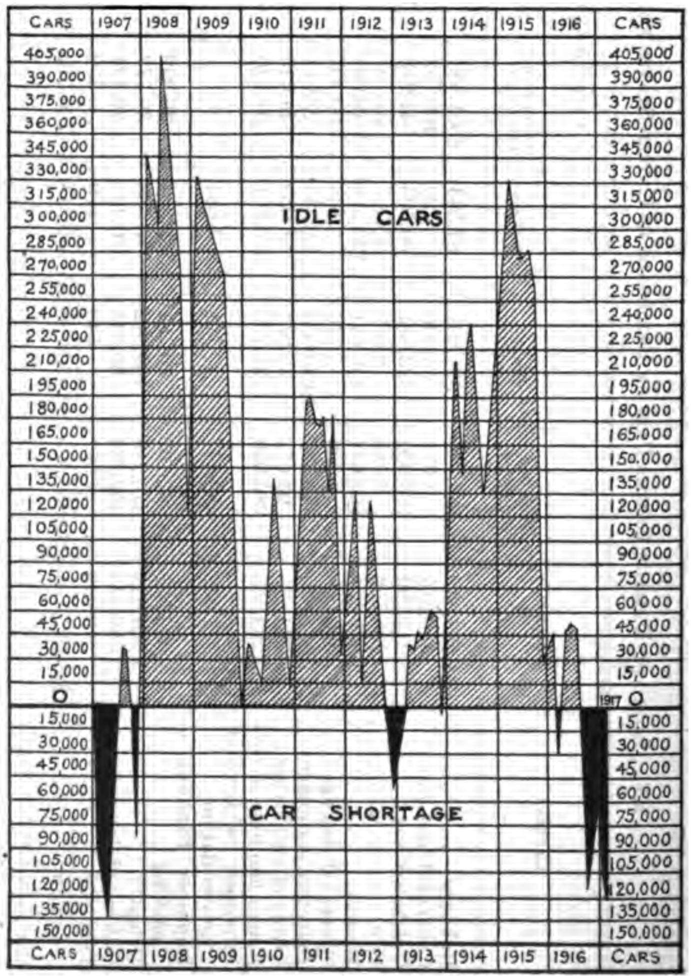
CAUSES	AMOUNT	PRINCIPAL ITEMS							
		Fruit and Vegetables	Grain	Live Stock	Clothing and Dry Goods	Furniture	Groceries	Flour, etc.	Meats
Robbery	$1,459,937	$33,124	$21,801	$1,544	$501,481	$6,040	$69,802	$8,081	$41,873
Concealed loss	519,215	3,674	3,496	120	266,752	5,021	12,226	4,994	6,386
Unlocated loss	5,913,290	185,950	523,881	50,503	541,918	145,927	455,302	139,180	200,977
Fire	608,753	8,085	18,079	27,367	52,757	14,510	13,307	7,581	1,694
Wrecks	1,577,474	109,644	148,611	153,718	49,608	19,943	35,563	36,788	125,550
Concealed damage	692,969	6,833	5,776	2,108	60,197	139,421	12,494	3,933	2,651
Defective equipment	2,577,879	42,571	1,080,953	32,335	22,011	19,254	63,061	517,040	11,684
Errors of employees	775,815	93,613	32,271	68,059	44,645	13,167	25,787	22,997	25,592
Rough handling of cars	3,299,665	285,936	27,236	325,361	34,146	320,731	142,039	82,924	31,544
Improper refrigeration or ventilation	771,062	489,877	798	1,684	—	—	10,298	—	126,017
Improper handling or packing	1,026,571	67,197	16,581	39,304	36,392	106,480	63,878	41,173	20,118
Delays	1,704,014	376,218	109,512	716,538	39,772	4,243	15,942	15,528	114,732
Unlocated damage	5,088,443	352,784	60,845	370,445	86,494	501,978	239,962	268,419	66,104
Penalties	10,046	1,067	540	179	339	430	620	593	306
Total	$26,025,134	$2,056,575	$2,050,380	$1,789,314	$1,736,512	$1,297,145	$1,160,281	$1,149,231	$775,228

XVI. Accidents and Losses caused by Explosives and Other Dangerous Articles

Year	Explosives				Other Dangerous Articles			
	Accidents	Deaths	Injuries	Losses	Accidents	Deaths	Injuries	Losses
1907	74	52	80	$496,820				
1908	22	26	53	114,629				
1909	12	6	7	2,673				
1910	16	2	1	43,636				
1911	10	1	5	34,761	399	11	21	$93,772
1912	9	0	6	10,200	326	8	15	328,380
1913	11	0	4	22,048	479	2	36	337,575
1914	11	0	7	14,106	508	13	109	278,118
1915	11	0	6	127	581	64	546	1,454,000

XVII. Car Shortage and Car Idleness, 1907–1917

American Railway Association



XVIII. Yield of Crude Petroleum in the United States 1915–1916. — Bbls.

	1915	1916
Oklahoma	97,915,243	105,100,000
California	86,591,535	89,000,000
Texas	17,467,598	26,000,000
Illinois	19,041,695	16,500,000
Louisiana	18,191,539	15,800,000
West Virginia	9,264,798	8,500,000
Pennsylvania	7,838,705	8,000,000
Ohio	7,825,326	7,400,000
Kansas	2,823,487	6,500,000
Wyoming — Montana	4,245,525	6,300,000
Kentucky	437,274	1,200,000
Indiana	875,758	1,000,000
New York	887,778	900,000
Colorado	208,475	190,000
Other states	14,265	10,000
Total	281,104,104	292,300,000

Oil Refineries in the United States — 1916

Estimated Daily Capacity (Bbls.) Crude Oil

	No. of Refineries	Capacity
California	76	211,300
Kansas	21	34,250
Oklahoma	41	105,075
Texas	23	179,800
Pennsylvania	56	109,470
New York	11	42,000
New Jersey	10	111,000
Miscellaneous	64	250,350
Total	302	1,043,245

(From "Age of Oil." Chas. A. Stoneham — 1917.)

XIX. Car Ferries on the Great Lakes and St. Lawrence River

Lake Michigan.	
Grand Trunk Railway.	
Grand Haven to Milwaukee	85 miles
Pere Marquette Railroad.	
Ludington to Milwaukee	95 miles
Ludington to Manitowoc	50 miles
Ann Arbor Railroad.	
Frankfort to Manitowoc	70 miles
Frankfort to Marinette	70 miles
Frankfort to Kewaunee	50 miles

XIX. Car Ferries on the Great Lakes and St. Lawrence River — *Cont.*

Lake Erie.
Pere Marquette Railroad.
Conneaut Harbor to Rondeau . . . . 80 miles
(Capacity, 30 cars.)
Conneaut Harbor to Port Stanley . . . . 60 miles

Lake Ontario.
Buffalo, Rochester & Pittsburgh Railway.
Genesee Dock, Charlotte, to Cobourg . . . . 55 miles
(Capacity, 30 cars, 1000 passengers.)

St. Lawrence River.
Ogdensburg to Prescott . . . .
(Capacity, 760 cars in 24 hours.)

XX. Port of New York — Occupation of Water Front

	Pier No. 1 to New Pier No. 48 2.23 Miles	Pier No. 1 to North Side 30th St. 3.91 Miles
	Per cent.	Per cent.
Transatlantic steamships	1.4	17.5
Coastwise steamships	15.6	24.3
Railroads	47.9	30.8
Hudson River boats	5.3	3.0
Sound boats	10.0	5.7
Ferries	9.5	7.8
Open wharfage	4.3	3.9
Coal, ice, etc.	5.8	6.9
Recreation pier	0.2	0.1

[1] "Problem of Lower West Side, Manhattan Water Front. Port of New York. February 21, 1912." B. F. Cresser, M. Am. Soc. C. E. International Engineering Congress, September, 1915.

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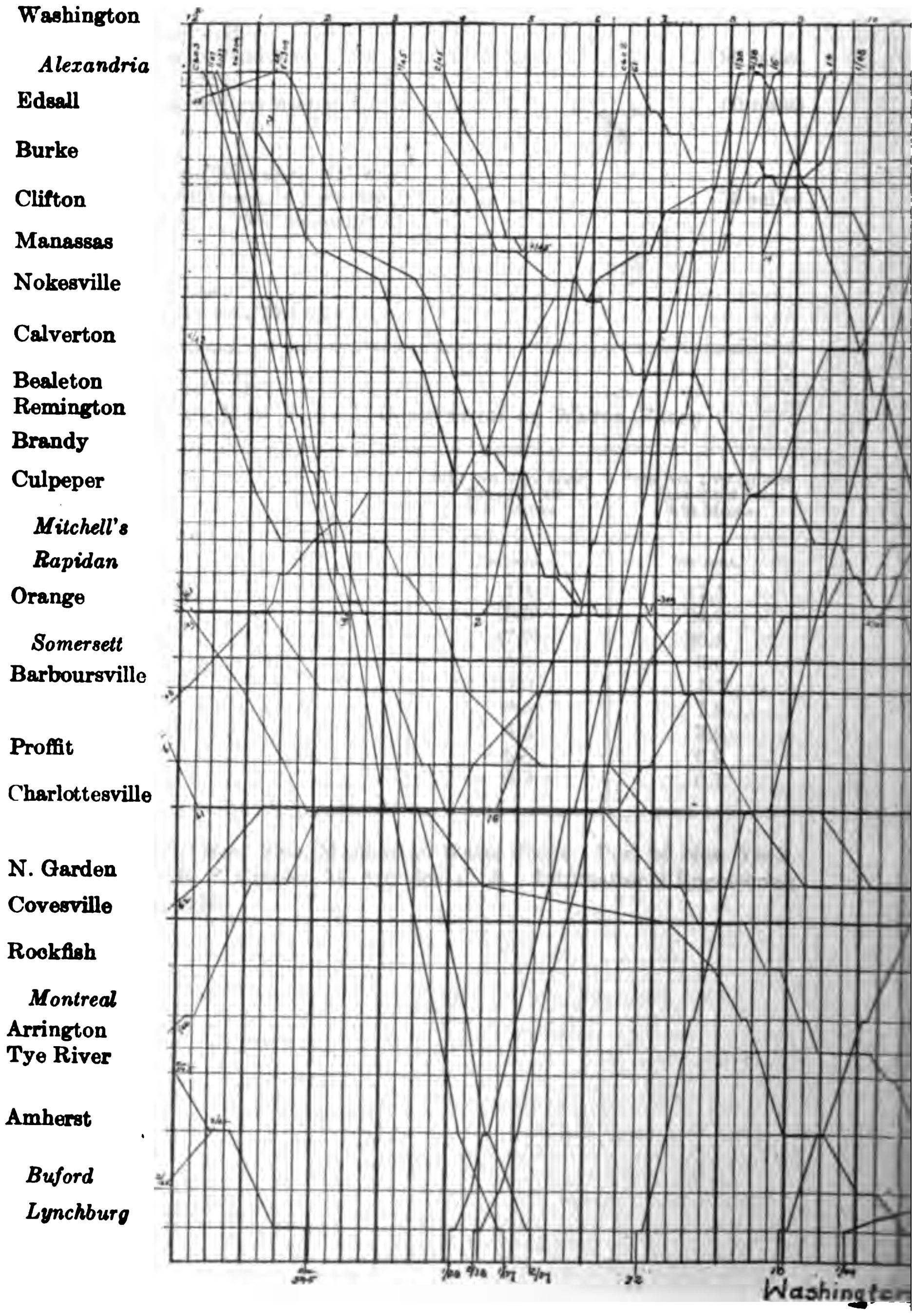
APPENDIX VII. PLATE I.

STATIONS

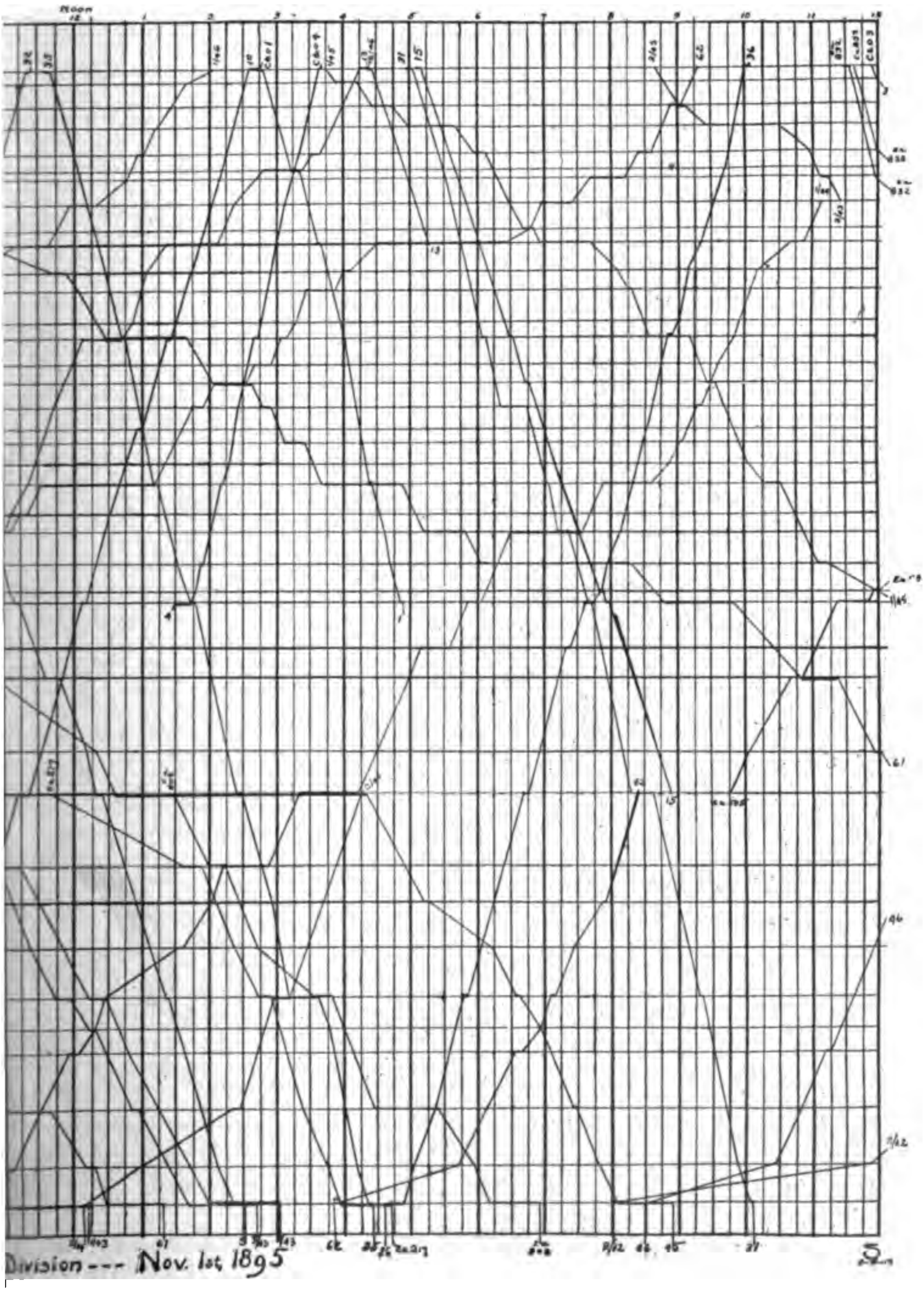
Single track.

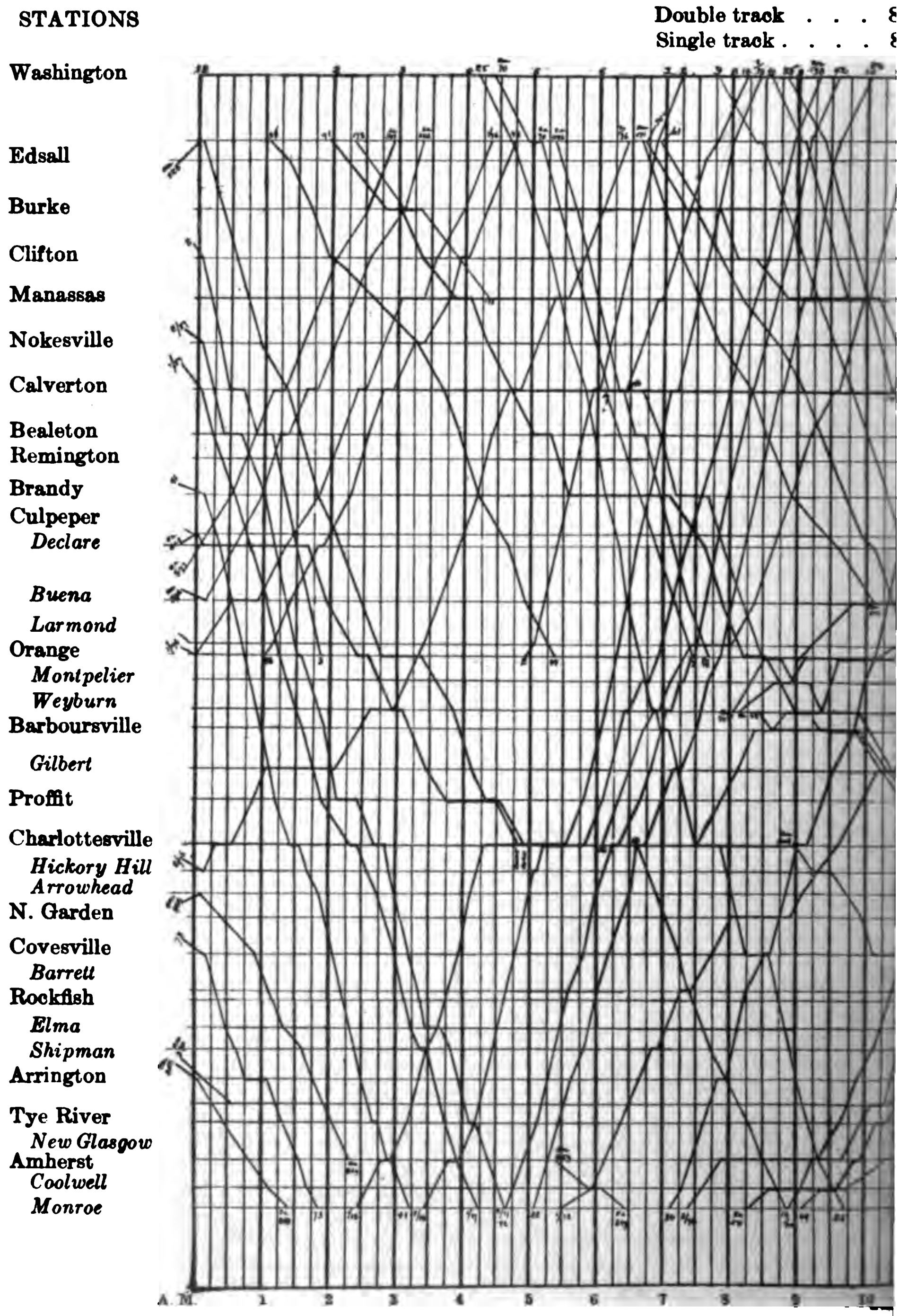
Washington to Ly



OUTHERN RAILWAY. WASHINGTON DIVISION.

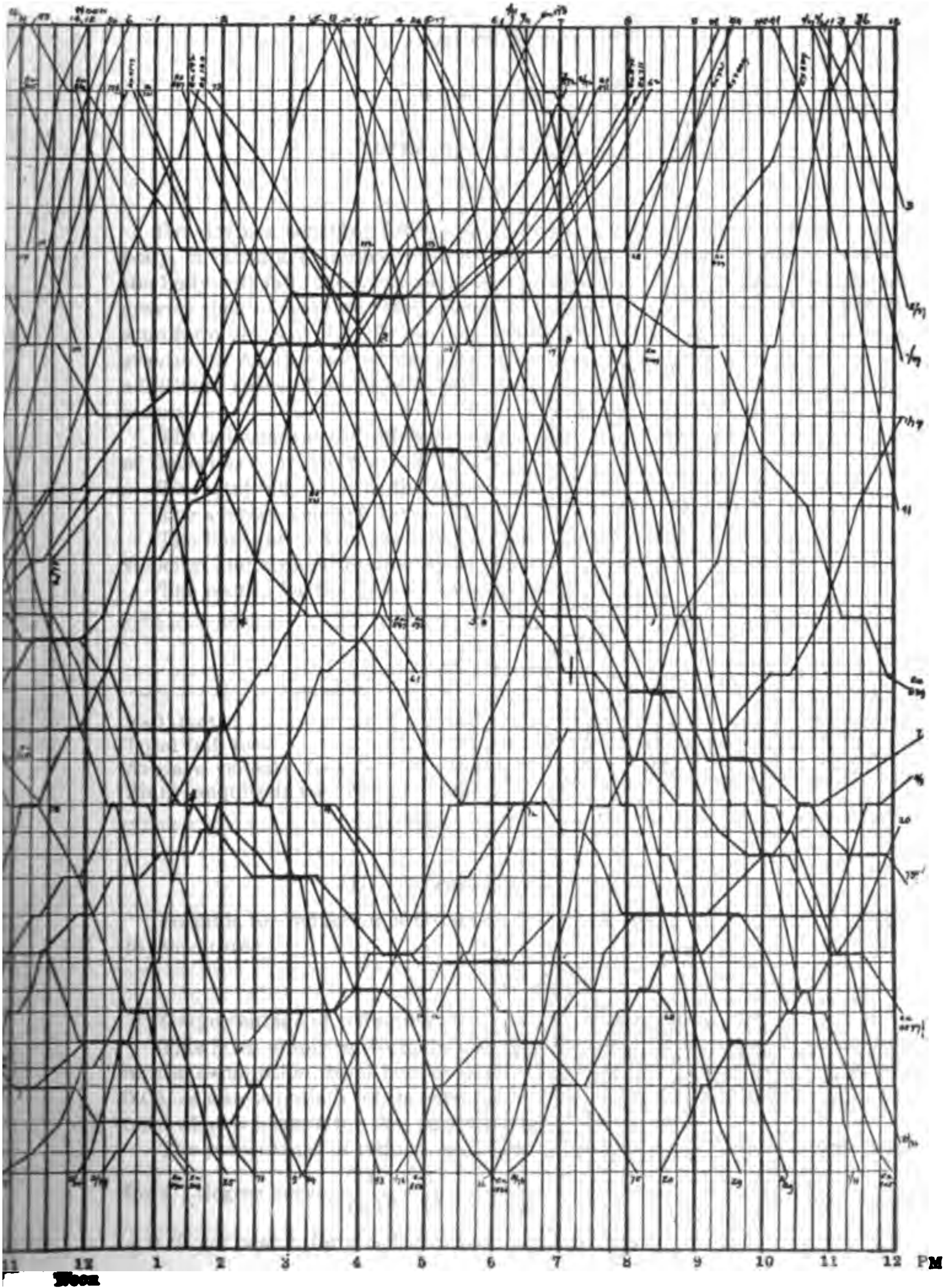
hburg, 174 miles Train-sheet for November, 1895.




STATIONS
Double track . . . 8
Single track 8
Washington
Edsall
Burke
Clifton
Manassas
Nokesville
Calverton
Bealeton
Remington
Brandy
Culpeper
Declare
Buena
Larmond
Orange
Montpelier
Weyburn
Barboursville
Gilbert
Proffit
Charlottesville
Hickory Hill
Arrowhead
N. Garden
Covesville
Barrett
Rockfish
Elma
Shipman
Arrington
Tye River
New Glasgow
Amherst
Coolwell
Monroe
A. M.
1
2
3
4
5
6
7
8
9
10

miles
miles

Train-sheet for November, 1913.



APPENDIX VII

TRANSPORTATION DATA

NOTES AND TABLES I TO XXV

I. EFFECT OF GRAVITY

Gravity is a constant force, and near the surface of the earth gives to a falling body, in vacuum, a uniformly accelerated motion. During the first second of time, the body will fall through a space or distance of 16.08 feet, and, were the force of gravity then to cease, the body would have acquired (at the end of the first second) a uniform velocity of 32.16 feet per second: this is known as the "acceleration of gravity." At the end of the next second the body will have fallen through an additional space of 48.24 feet, and will have acquired a velocity of 64.32 feet per second.

The fall varies as the difference between squares of the times, or twice the number of times less one: $16.08 \times 1, 3, 5, 7$, etc.

The total fall varies as the squares of the times: $16.08 \times 1, 4, 9, 16$, etc.

The average velocity varies directly as the times: $16.08 \times 1, 2, 3, 4$, etc.

The final (at end of each second) or acquired velocity is double the average velocity, and also varies directly as the times: $32.16 \times 1, 2, 3, 4$, etc.

The results for the first six seconds are as follows:

	1st Second	2d Second	3d Second	4th Second	5th Second	6th Second
Fall, feet	16.08	48.24	80.40	112.56	144.72	176.88
Total fall, feet	16.08	64.32	144.72	257.28	402.00	577.88
Average velocity, feet	16.08	32.16	48.24	64.32	80.40	96.48
Final (acquired) vel., feet	32.16	64.32	96.48	128.64	160.80	192.96

II. COMPENSATION FOR CURVATURE

Formula for reduction of Gradient as compensation for increased resistance due to curvature:

$$C = \frac{D}{D+18}$$

C = percentage of reduction. D = degree of curve.

This is an empirical formula, for special application to ruling gradients, based on the assumption, from best available data, that by reducing the gradient about 0.05, or one-twentieth, of its rate, for a 1-degree curve, the resistance will then be only what is normal for that gradient on a tangent.

The percentages of reduction in gradient rate, given by the above formula, are for a 1-degree curve, $\frac{1}{1+18} = \frac{1}{19} = 0.53$ per cent.; for a 2-degree curve, $\frac{2}{2+18} = \frac{2}{20}$ $= 0.10$ per cent.; for a 5-degree curve, $\frac{5}{5-18} = \frac{5}{23} = 0.218$ per cent., etc.

The actual reductions for curves of different degree, on a 1 per cent. gradient, or 52.8 feet per mile, would be:

For a 1-degree curve, $52.8 \times 0.53 = 2.8$; $52.8 - 2.8 = 50.0$ ft. per mile.
For a 2-degree curve, $52.8 \times 0.10 = 5.28$; $52.8 - 5.28 = 49.52$ ft. per mile.
For a 5-degree curve, $52.8 \times 0.218 = 11.5$; $52.8 - 11.5 = 41.3$ ft. per mile.

"Curves are commonly equated between 0.02 per cent. and 0.10 per cent. of gradient per degree of curve, and 0.05 per cent. is largely used where the speed is slow." — "Traction of Freight Trains at Different Speeds." C. S. Bissell, M. Am. Soc. C. E. Trans. Am. Soc. C. E., March, 1910, p. 58.

Droege, "Freight Terminals," p. 154, states that "the best practice appears to be to consider that the resistance due to a 1-degree curve is practically the same as on a 0.04 per cent. grade, and for a 2-degree curve it is twice as much. Since the resistance due to grade is 20 pounds per ton for a 1 per cent. grade, for a 0.04 per cent. grade it will amount to 0.8 pound per ton. So that the resistance due to a 1-degree curve could just as readily be represented as 0.8 pound per ton of train."

Although, in fact, curve-resistance does not vary uniformly with the degree of the curve, the above statement is probably sufficiently exact, for the adjustment of train-loads, where there has been no compensation for curvature on gradients.

For example, if a maximum curve of 6 degrees occurs on a 0.4 per cent. grade, then

Resistance due to grade, — $0.4 \times 20 = 8.0$ pounds per ton.
Resistance due to curvature, — $6 \times 0.8 = 4.8$ pounds per ton.
Total resistance, 12.8 pounds per ton.

That is, the draw-bar pull on level straight track would be increased on such a maximum grade and curve 12.8 pounds for every ton of train-weight.

III. Formula for Grade-Resistance

Grade-resistance, or the "decelerating" force, bears the same relation to the total weight of train that the rise in a given distance does to the length of the grade.

Let F = grade-resistance, and W = weight of train; AC = vertical height of ascent, and BC = length of grade.

Then

$$\frac{F}{W} = \frac{AC}{BC}$$

If $BC = 100$ and $AC = R$, or the ratio of the rise of grade, then

$$\frac{F}{W} = \frac{R}{100} \text{ and } F = \frac{WR}{100}.$$

If $W = 2000$ pounds, then $F = 20\,R$, or the grade-resistance in pounds per ton = the per cent. of grade $\times$ 20, or twice the rate of grade expressed in tenths.

For example, on a 1 per cent. grade the resistance is 1×20, or 20 pounds per ton. On a 0.4 per cent. grade the resistance is 0.4×20, or 8 pounds per ton.

For the ton of 2240 pounds, add 12 per cent.

See "Railway Location," Wellington, p. 140.

IV. Resistance for Various Speeds and Different Car-Weights

A. Results obtained by Prof. E. C. Schmidt, University of Illinois.

Trains at uniform speed on a level tangent. Temperature not less than 30 degrees Fahrenheit, and wind velocity not exceeding 20 miles per hour.

TRAIN RESISTANCE IN POUNDS PER TON

Miles per Hour	Average Weight in Tons per Car in Train							
	15	20	25	30	35	40	45	50–75
5	7.6	6.8	6.0	5.4	4.8	4.4	4.0	3.7–3.0
8	8.0	7.1	6.3	5.6	5.0	4.6	4.2	3.9–3.1
10	8.2	7.3	6.5	5.8	5.2	4.7	4.3	4.0–3.2

Condensed from "Freight Terminals," 1911, p. 156.

From the above, it appears that as the cars increase in weight, the resistance decreases. At 5 miles per hour the resistance for lighter cars (15 tons) was 7.6 pounds per ton, but decreased to 3.0 pounds per ton for the heaviest (75 tons). At 8 miles per hour the resistances of the same cars were 8.0 pounds per ton and 3.1 pounds per ton, respectively; and at 10 miles per hour, 8.2 pounds per ton and 3.2 pounds per ton, respectively. The increased resistance with increase of speed from 5 to 10 miles per hour was 0.6 pound per ton for the lighter cars, but only 0.2 per ton for the heaviest. The decrease between extremes at 5 miles per hour was 4.6 pounds per ton, and at 10 miles per hour 5 pounds per ton; or about 60 per cent. in either case.

B. Pennsylvania Railroad. Tests of Draw-bar Pull.

LOCOMOTIVE, WITH TENDER, WEIGHING 168 TONS. CARS OF 40-TON CAPACITY

Miles per Hour	Draw-bar Pull	
10	32,100 lb.	100 per cent.
16	22,370 lb.	69 per cent.
30	10,350 lb.	32 per cent.

TRAIN RESISTANCE AT DIFFERENT SPEEDS WITH 52 LOADED BOX CARS. TARE, 37 PER CENT. OF GROSS WEIGHT

Miles per Hour	Resistance in Pounds per Ton
15	4.50
25	4.73
35	5.00

This test "differs radically from the results obtained by Wellington and other authorities, experimenting with light trains, cars and rails." — "Traction of Freight Trains," C. S. Bissell. Trans. Am. Soc. C. E., March, 1910, p. 60.

The total train-resistance for a passenger-train of 8 or 9 cars, weighing 200–210 tons, at 45 miles an hour, is about 12 pounds per ton; and of a freight-train of 20 to 25 cars of 20,000 pounds' capacity each, averaging 12 to 14 tons empty, at a speed of 16 to 18 miles an hour, is from 8 to 10 pounds per ton.

The above facts were determined by Dr. P. H. Dudley in dynamometer-tests made on the first track laid with Bessemer steel rail on the New York Central & Hudson River Railroad, and they agree very well with the experimental tests by Professor Schmidt for freight-trains, and with the practice of the Pennsylvania Railroad as to passenger-trains.

V. Resistance of Passenger Trains

In a test by Dr. P. H. Dudley, in 1882, on the New York Central & Hudson River Railroad, only about 45 per cent. of the locomotive's 750–800 indicated horse-power passed back of the dynamometer-car, at a speed of 53 miles an hour. The tractive power, at starting, of 11,000–12,000 pounds fell to 2800–3000 pounds at 50 miles an hour. In this test, the resistance of both the locomotive and the atmosphere was established empirically at 0.083 per cent. of the square of the velocity, and on this basis the following table was prepared.

Locomotive Resistance

Miles per Hour	Resistance—Lb.	Horse-power Required	Lb. per Ton of Train — 313 Tons
10	83	2.213	0.266
20	332	17.71	1.06
30	747	59.77	2.38
40	1,328	141.67	4.25
50	2,075	276.70	6.64
60	2,988	478.20	9.58
70	4,067	759.30	13.05

To this "head-resistance" is to be added the constant frictional resistance, from 4 to 8 pounds per ton, and the proportionate grade-resistance. The velocity-resistance increases as the square of the velocity, and the horse-power as its cube. The power of the locomotive, in this test, would have been exhausted in maintaining the speed of itself only, at 70 miles an hour. — (See "Railway Location," pp. 519–522.)

Experimental tests were made by Professor E. C. Schmidt with 187 cars, of which 155 had 6-wheel trucks. Average weight, 40 tons. These cars were made up in 18 trains of 8 to 12 cars, weighing from 487 to 711 tons. The trials were made on a run of 124.5 miles, and in a temperature between 69 degrees and 93 degrees Fahrenheit. On level track, the mean resistance was as follows:

Speed, miles per hour . . .	10	20	30	40	50	60	70
Mean resistance, pounds per ton	5.5	6.1	6.7	7.5	8.5	9.7	11.5

See Railway Age Gazette, March 9, 1917.

Effect of Variation in Speed upon Draw-bar Pull

Locomotive of Consolidated Type (2–8–0), 113,000 Lbs. on 50-Inch Driving-wheels, 150 Lbs. Steam Pressure, 20″ × 28″ Cylinders.

Miles per Hour	Draw-bar Pull		Weight of Train—Tons	Miles per Hour	Draw-bar Pull		Weight of Train—Tons
	Pounds	Per Cent. of Total			Pounds	Per Cent. of Total	
5	24,600	100	5,300	20	0,300	42	2,220
12	18,000	73	3,870	25	7,800	32	1,680
14	16,000	65	3,440	29	6,200	25	1,330
15	14,600	60	3,140	32	5,300	22	1,140
16	13,600	55	2,920	34	4,800	20	1,030
17	12,800	52	2,750	38	4,000	17	860
18	12,000	49	2,580	41	3,500	14	750

For Draw-bar Pull, see "Economics of Railway Operation," 1907. M. L. Byers, p. 500. Train-resistance estimated at 4.65 pounds per ton.

VI. Comparison of Estimated and Actual Performance of Freight Locomotives

The present practice of one of the principal locomotive shops in this country in estimating the tonnage-capacity of locomotives is shown in the following example:

For a locomotive with cylinders 21″ diameter by 26″ stroke, with 115,000 pounds weight on 60-inch driving wheels and a boiler-pressure of 200 pounds, the available tractive power is estimated at 25,587 pounds, as per Appendix II, Table XVIII. Assuming the resistance of a car weighing, when loaded, 58 tons, to be 4.65 pounds per ton for a speed of 10 miles an hour, the tonnage-capacity of such a locomotive, on a straight and level track, would be estimated at $\frac{23,801}{4.65} = 5119$ tons of gross trainload, or a train of 88 cars. On a ruling grade of 1 per cent., the resistance would be 20 pounds per ton, and the rating would be $\frac{23,801}{4.65+20} = \frac{23,801}{24.65} = 915$ tons, or a train of 16 loaded cars of 40-ton capacity (weighing gross 58 tons).

The following comparison of estimated performance on this assumption of train-resistance with actual performance is based upon a statement of the performance of freight-locomotives on the Pennsylvania Railroad, taken from a paper on "Maximum Weight of Slow Freight Trains," by C. E. Bissell, M. Am. Soc. C. E., in Transactions of Am. Soc. C. E., Vol. LXIV, September, 1909, p. 303.

The type of locomotive here considered weighed, with tender, 168 tons, with 173,000 pounds on driving wheels. The coefficient of adhesion was determined experimentally as 0.232 of this weight, and the coefficient of tractive power, at a speed of 10 miles an hour as 0.863 of this amount ($0.232 \times 0.863 = 0.20016$). The resulting estimate of available tractive power was placed at $173,000 \times 0.2 = 34,600$ pounds. Dividing this by 4.65 (train-resistance in pounds per ton) and deducting weight of locomotive and tender, $\frac{34,600}{4.65} - 168 = 7,272$ tons, tonnage-rating on a straight and level track, with tender draw-bar pull of 33,816 pounds.

Gradients Per Cent.	Estimated			Actual		
	Tonnage	Cars	Percentage of Level-Track Tonnage	Tonnage	Cars	Percentage of Level-Track Tonnage
Level	7,272	97	100			
0.300 per cent.	3,175	42	43.6	3,292	43	45.2
0.655 " "	1,905	25	26.2	1,898	26	26.1
1.055 " "	1,313	17	18.0	1,238	16	17.0
1.260 " "	1,132	15	15.5	953	12	13.1
2.130 " "	721	9	9.9	555	7	7.6

The number of cars in the train is based on 75 tons for a loaded car (20 tons empty). The agreement between estimated and actual tonnage is practically close, up to the gradient of 1.055 per cent.; beyond that, there is a divergence equivalent to an increased train-resistance of 10.3 pounds per ton for a gradient of 1.26 per cent., and of 18.3 pounds per ton for a gradient of 2.13 per cent., at a speed of 10 miles an hour.

Thus, over an ascending ruling-gradient of 0.3 per cent. (16 feet per mile) a locomotive of the type above given, with 33,816 pounds net tractive power, could take a train of 43 loaded cars, weighing 3292 tons, at a speed of 10 miles an hour; but only 26 cars, weighing 1898 tons, at the same speed, up an exceptional gradient of 0.655 per cent. (35 feet per mile), and the difference of 17 cars, 1394 tons, would require the aid of a pusher of 25,023 pounds net tractive power; while on a 1.055 per cent. gradient (56 feet per mile) the same locomotive could take only 16 cars, 1238 tons, at the same speed, and the difference in load of 27 cars, 2054 tons, would call for a pusher of 57,487 pounds net tractive power, or, rather, two locomotives of combined power equal to that deficiency.

RATING SHEET. Locomotive Consolidated Type (2-8-0), 22″×28″ cylinders. Steam-pressure, 200 pounds. Total weight, 144 tons. Weight on driving-wheels, 155,156 pounds.

Grade	Rating — Tons			
	Summer	Winter		
0.38 per cent.	2,850	2,485	2,500	2,963
0.50 " "	2,424	2,155	2,115	2,510
0.70 " "	1,940	1,840	1,664	1,971
1.00 " "	1,492	1,386	1,259	1,492
1.10 " "	1,386	1,292	1,171	1,380
1.20 " "	1,292	1,212	1,012	1,199
1.40 " "	1,140	1,078	952	1,126

L. A. Riley, 2nd, — Trans. Am. Soc. C. E., September, 1909, p. 312.

A locomotive with a weight of 155,156 pounds on the driving-wheels should deliver a tender draw-bar pull of 155,156×0.2 = 31,031 pounds, which, divided by 4.65 (pounds per ton train-resistance) gives a gross train-weight of 6,670 tons on a level track. The estimated rating for gradients on this basis is here incorporated in the rating-sheet for purposes of comparison.

VII. SIGNAL INDICATIONS

Standard Code. American Railway Association.

BLOCK SYSTEM

The signals are displayed over or on the right-hand (usually) of the running track, facing toward an approaching train.

ABSOLUTE BLOCK

Home Signal — in two positions.
  Horizontal — Stop.
  Inclined — Proceed.
Distant Signal — in three positions.
  Horizontal — Approach home signal prepared to stop.
  Inclined — " " " at reduced speed.
  Vertical — " " " at full speed.

PERMISSIVE BLOCK

Home Signal — in three positions.
  Horizontal — Stop.
  Inclined — Proceed prepared to stop short of obstruction or train ahead.

COLOR INDICATIONS AT NIGHT

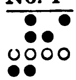
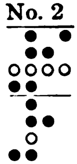
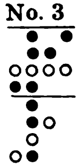
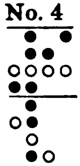
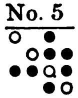
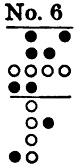
Red — Stop.
Green — Caution.
White — Proceed.

On many lines, a yellow or amber-colored light is substituted for white, to avoid confusion with other white lights in the vicinity.

Also, on many other lines, green is used for proceed, and amber-colored (yellow) for caution, — white, in a fixed signal, indicating a broken lamp or danger.

STANDARD ASPECTS OF POSITION-LIGHT SIGNALS

Pennsylvania Railroad. April 1, 1918.

Aspect	Signal	Remarks
No. 1 	Stop	
No. 2 	Stop and proceed (Rule 504)	
No. 3 	Proceed at low speed prepared to stop	Not used in same territory as No. 4
No. 4 	Proceed at low speed prepared to stop short of train or obstruction (Permissive)	Used only in Manual Block Territory
No. 5 	Proceed with caution prepared to stop short of train or obstruction (Permissive)	Not used in same territory as No. 7
No. 6 	Proceed at medium speed	

STANDARD ASPECTS OF POSITION-LIGHT SIGNALS — *Continued*

Aspect	Signal	Remarks
No. 7 ● ○ ●○ ●○●● ●○	Proceed prepared to stop at next signal	Not used in same territory as No. 5
No. 8 ● ○ ●○ ●○●● ○● ○ ○● ○ ●○	Proceed prepared to pass next signal at medium speed	
No. 9 ○ ● ○● ●○●● ●○	Proceed	
No. 10 ○ ○ ○ ○ ○	Take siding	Displayed by itself at height of ten feet

DWARF SIGNALS

Aspect	Signal	Remarks
No. 1 ○○ ●	Stop	
No. 3 ●○ ○	Proceed at low speed prepared to stop	
No. 11 ○● ○	Proceed at low speed	

Medium speed — Not exceeding 30 M. P. H.
Low speed — Not exceeding 15 M. P. H.

The principal aspects of Nos. 1, 7, and 9 are displayed by the primary group of ten units.
The secondary group of six units is only necessary when locally required.

TRAIN SIGNALS

Flags by Day.
Combination lamps with four colored faces at night.

Extra Engine as a Train

By Day — White Flags, one on each side of engine-front.
By Night — White Lights and White Flags, one on each side of engine-front.

Extra Engine Running Backward, or at Rear of a Train, Pushing Cars

By Day — White Flags on sides of engine-front. Green (or Yellow) Flags on bumper as Markers.

By Night — White Lights and White Flags on engine-front. Lamps on bumper as Markers, showing Green Lights (or Yellow) at side and in direction of engine's movement, and Red toward rear.

Engine Displaying Signals for Following Section

By Day — Green Flags, on sides of engine-front.

By Night — Green Lights and Green Flags on engine-front.

Engine Running Backward, Displaying Signals for Following Section

By Day — Green Flags, one on each side of engine-front, and on each end of bumper.

By Night — Green Flags and Green Lights on engine-front, and lights on bumper as Markers, showing Green (or Yellow) at side and in direction of engine's movement, and Red toward rear.

Engine Running Forward, without Train, or at the Rear of a Train, Pushing Cars

By Day — Green (or Yellow) Flags, one on each side of rear of tender, as Markers.

By Night — Lamps, one on each side of rear of tender, showing Green (or Yellow) Light at side and toward front, and Red toward rear.

Engine Running Backward, without Train, or at the Front of a Train, Pulling Cars

By Night — White Light on rear of tender, over center line of track.

Passenger Cars Pushed by an Engine

By Night — White Light on front platform of leading-car.

Freight Cars Pushed by an Engine

By Night — White Light on front of leading-car.

At the Rear of a Train — by Night

While running — Lights on each side, as Markers, showing Green (or Yellow) toward engine and at side, and Red toward rear.

While on siding, to be passed by another train — Lights, one on each side, as Markers, showing Green (or Yellow) toward engine, at side, and toward rear.

HEAD-LIGHT must be concealed, when train is standing, to meet trains, or at end of double-track, or at junctions.

YARD-ENGINES display head-light at front and rear.

DOUBLE-TRACK OPERATION

Rear of Train Running against the Current of Traffic

By Night — Lights as Markers, Green (or Yellow) toward front and at side; but Green toward the rear on the side next to the main track on which the current of traffic is in the direction of the moving train, and Red toward the rear on the opposite side.

LOCOMOTIVE WHISTLE SIGNALS

"o" for short sounds; "—" for longer sounds

Sound	Indication
o	Apply brakes. Stop.
— —	Release brakes. Proceed.
— o o o	Flagman protect rear of train.
— — — —	Flagman may return from West or South.
— — — — —	" " " " East or North.
— — —	Train parted. — To be repeated.
o o	Answer to signal, not otherwise provided for.
o o o	When train is standing, back. Answer to conductor's signal to back.
o o o o	Call for signals.
— o o	To call attention to signals displayed for a following section.
— — o o	Approaching public crossings.
————	Approaching stations, junctions and railroad crossings.
o —	Inspect train-line for air leak.
Quick succession of short sounds	Alarm for persons or livestock on track.

Engine bell must be rung when an engine is about to move, and while approaching and passing public crossings.

CONDUCTOR'S AIR-WHISTLE SIGNALS

"o" for short sounds; "——" for longer sound

Sound	Indication
o o	When standing — Start.
o o	When running — Stop at once.
o o o	When standing — Back the train.
o o o	When running — Stop at next station.
o o o o	When standing — Apply, or release, air-brakes.
o o o o	When running — Reduce speed.
o o o o o	When standing — Recall flagman.
o o o o o	When running — Increase speed.
o o o o o o	When running — Increase train-heat.
————	When running — Look back for hand signals.

HAND SIGNALS

By flag, lamp, or hand only

Manner of Using	Indication
Swung across the track.	Stop.
Held horizontally at arm's length, when train is moving.	Reduce speed.
Raised and lowered vertically.	Proceed.
Swung vertically in a circle, at half arm's length, across the track, when train is standing.	Back.
Swung vertically in a circle, at arm's length, across the track, when train is running.	Train has parted.
Swung horizontally, above the head, when train is standing.	Apply air-brakes.
Held at arm's length above the head, when train is standing.	Release air-brakes.

TRACK SIGNALS

A train finding a fusee burning on or near its track, must stop and extinguish the fusee, and then proceed with caution, prepared to stop short of obstruction or train ahead.

Any object waved violently by any one, on or near the track, is a signal to stop.

The explosion of torpedoes is a signal to reduce speed and look out for an obstruction or a train ahead.

A blue signal, displayed at one end or both ends of an engine or train or car, indicates that workmen are under or about it.

A green-and-white signal will be used to stop a train at flag-stations. To stop a train at other points, a red flag or red light will be used.

VIII. Railroad War-Efficiency

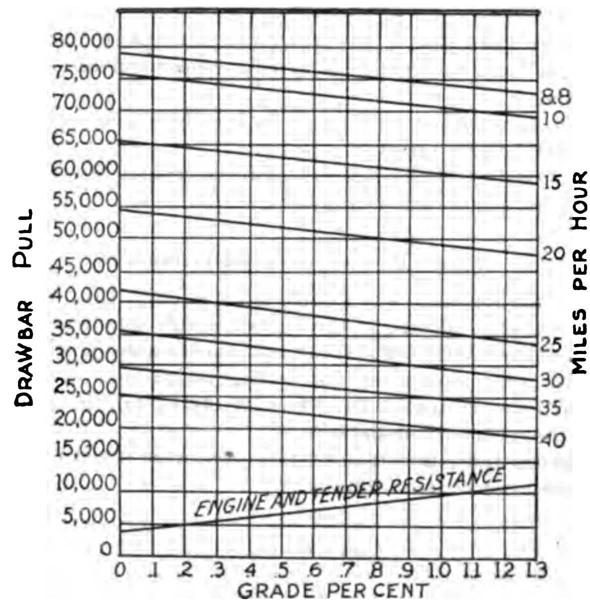
In a report to the Railroad War Board, made in July, 1917, roads representing 51 per cent. of the total mileage in the United States were shown to have added in one month more than 3,000,000,000 ton-miles to the mileage of the corresponding month in 1916, by better movements and by heavier loading. This was an increase of 10 per cent., and was equivalent to adding 126,000 cars to the total equipment, or 35,000 miles to the reported line-mileage.

In one freight-yard, the first ten cars inspected were found to be loaded to but 47 per cent. of their capacity, as follows:

Car	Capacity — Lb.	Load — Lb.
1	80,000	10,780
2	110,000	78,600
3	60,000	24,800
4	100,000	12,880
5	100,000	21,440
6	140,000	110,432
7	140,000	144,900
8	60,000	13,320
9	100,000	16,408
10	50,000	9,775
	940,000	443,335

IX. Draw-bar Pull as Affected by Speed and Gradients

From Baldwin Locomotive Works



X. Grades of Repose for Passenger Trains

Locomotive, American Type (4-4-0)-Cylinders, 17″ × 24″. Cars averaging 25 Tons Each

Train	Weight Tons	Grade Per Cent. for Velocities in Miles per Hour						
		15	20	25	30	40	50	60
Locomotive only	56	0.60	0.88	1.24	1.69	2.81	4.26	6.03
with 2 cars	112	0.45	0.62	0.83	1.08	1.74	2.58	3.62
with 4 cars	168	0.40	0.52	0.69	0.88	1.38	2.02	2.81
with 8 cars	280	0.36	0.46	0.58	0.73	1.10	1.58	2.12
with 12 cars	392	0.34	0.42	0.53	0.65	0.98	1.39	1.89
with 16 cars	504	0.33	0.41	0.50	0.62	0.91	1.28	1.74

The "grade of repose" is the grade equivalent to the addition which the train-resistance makes to the actual plus or minus actual grade-resistance, either ascending or descending the grade. "Railway Location," p. 579.

Example: By reducing the speed of a passenger train of four cars from 30 to 20 miles an hour, there is a virtual difference in gradient of 0.88 per cent. −0.52 per cent. =0.36 per cent. By this reduction in speed, a train that at a speed of 30 miles an hour could ascend a grade of only 26.4 ft. to the mile, might ascend a grade of 36 ft. to the mile at a speed of 20 miles an hour.

XI. Lift of Passenger Trains on Ascending Grades, Due to Momentum Only

Miles per Hour	Vertical Lift in Feet	Length of Movement in Feet	
		On 0.5 Per Cent. Grade	On 1.0 Per Cent. Grade
10	3.55	710	355
15	7.99	1,598	799
20	14.20	2,844	1,420
25	22.20	4,440	2,220
30	31.95	6,390	3,195
35	43.40	8,680	4,340
40	56.80	11,360	5,680
45	71.89	14,378	7,189
50	88.75	17,750	8,875
60	127.80	25,560	12,780

A train approaching a grade at a given speed, and with steam shut off at the foot of the grade, would ascend the grades designated in the above table for the distances therein given, before coming to a state of rest, in accordance with the law of gravitation, as the train-resistance, due to journal friction and track-resistance, would be constant, atmospheric resistance being disregarded.

See "Railway Location," p. 335.

XII. Distance in Feet at which a Certain Velocity is Attained by a "Drifting" Train

Gradient Per Cent.	25 Miles an Hour				30 Miles an Hour			
	Initial Velocity — Miles				Initial Velocity — Miles			
	0+	10	15	20	0+	10	15	20
0.5	222	187	143	80				
0.6	111	94	71	40	320	284	240	178
0.7	74	63	48	27	160	142	120	89
0.8	56	47	36	20	107	95	80	60
0.9	45	38	29	16	80	71	60	45
1.0	37	33	24	14	64	57	48	36
1.5	21	17	13	8	32	29	24	18
2.0	14	12	10	5	22	20	16	12

Compiled from "Railway Location" — Table 122, p. 372.

XIII. CAR CAPACITY OF COMMODITIES IN POUNDS

Articles	Length of Car		
	34 Feet	36 Feet	40 Feet
Agricultural implements	28,000	30,000	34,000
Barrels	11,500	12,000	13,500
Baskets, nested	4,700	5,000	5,500
Boxes, wooden	15,000	16,000	18,000
Cans, tin	9,500	10,000	11,000
Doors and sash	23,500	25,000	28,000
Fencing wire	23,500	25,000	28,000
Furniture, wooden	15,000	16,000	18,000
Furniture, iron	23,500	25,000	28,000
Glass	13,000	14,000	16,000
Grain products	33,000	35,000	39,500
Iron ware	19,000	20,000	22,500
Machines and Machinery	19,000	20,000	22,500
Stoves	19,000	20,000	22,500
Vehicles, buggies	7,500	8,000	9,000
Vehicles, wagons	17,000	18,000	20,000

"Economics of Railway Operation," p. 533.

XIV. RATING, AT A SPEED OF TEN MILES AN HOUR, OF A LOCOMOTIVE WITH 36,000 POUNDS DRAW-BAR PULL

	Gross Weight of Car			
	20 Tons	30 Tons	40 Tons	50 Tons
Resistance on level track — pounds per ton	7.3	5.8	4.7	4.0
Resistance on ruling-grade — pounds per ton	28	22	18	15.3
Tonnage rating — tons	1,286	1,636	2,000	2,353
Cars in train — number	64	56	50	47
Empty weight per car — tons	11	15	17	19
Net load per car — tons	9	15	23	31
Net load of train — tons	576	840	1,150	1,457
Proportion of net tonnage	50	73	100	127

The resistance per car per ton on level track is taken from the experimental tests referred to in Note IV (Appendix VII).

The rating on ruling-grade is assumed at 2000 tons in train of 50 cars of 40 tons gross weight.

$\frac{36000}{50} = 720$ pounds draw-bar pull per car for 40-ton cars. $\frac{720}{40} = 18$ pounds per ton, train resistance on the ruling grade.

Rating for cars of other gross weights on same grade is based on the relative resistance on level track, and the tonnage-rating accordingly.

If a train of cars of 40 tons gross weight when fully loaded were loaded only to a gross weight of 30 tons, the rating would be reduced from 2000 tons gross, and 1150 tons net, in 50 cars, to 1636 tons gross; and, as the empty weight would be 56.6 per cent. of 30 tons, the net tonnage would be only 710 tons in 54 cars, or about 13 tons per car, instead of 23 tons, with the profitable use of tractive power reduced in the proportion of 1150 to 710, or nearly 40 per cent. Such is the effect of not loading cars to their normal capacity.

XV. Typical Variations in Empty Car Mileage

Railroads	Mileage	
	Loaded — Per cent.	Empty — Per cent.
Eastern District		
Hocking Valley	57	43
New York, New Haven & Hartford	71	29
Pere Marquette	71	29
Grand Rapids & Indiana	73	27
Atlantic City	73	27
Southern District		
Virginian	53	47
Carolina, Clinchfield & Ohio	56	44
Southern	71	29
Mobile & Ohio	72	28
Cincinnati, New Orleans & Texas Pacific	73	27
Yazoo & Mississippi Valley	74	26
Western District		
Butte, Anaconda & Pacific	52	48
Duluth & Iron Range	53	47
Duluth, Missabe & Western	55	45
Midland Valley	57	43
Chicago, Rock Island & Pacific	71	29
Chicago Great Western	71	29
Chicago, Milwaukee & St. Paul	71	29
Gulf, Colorado & Santa Fé	71	29
St. Louis & Iron Mountain Southern	72	28
Atchison, Topeka & Santa Fé	72	28
Oregon Short Line	72	28
Union Pacific	73	27
Duluth, South Shore & Atlantic	73	27
Galveston, Harrisburg & San Antonio	74	26
Northwestern Pacific	74	26
Minneapolis, St. Paul & Sault Ste. Marie	75	25
Northern Pacific	75	25
Oregon-Washington Line	76	24
Kansas City Southern	79	21
Spokane, Portland & Seattle	88	12

XVI. Typical Car Loadings

Railroads	Av. Load Tons
New England Lines	
Boston & Maine	15.8
New York, New Haven & Hartford	15.5
Trunk Lines	
Pennsylvania	28.2
Baltimore & Ohio	25.3
Erie	21.4
New York Central & Hudson Riv.	18.3
Anthracite Coal Lines	
Philadelphia & Reading	28.4
Central of New Jersey	28.0
Lehigh Valley	24.0
Delaware, Lackawanna & Western	23.3
Delaware & Hudson	25.6
Bituminous Coal Lines	
Bessemer & Lake Erie	44.7
Pittsburgh & Lake Erie	35.0
Wheeling & Lake Erie	33.2
Buffalo, Rochester & Pittsburgh	35.7
Virginian	45.5
Norfolk & Western	31.6
Chesapeake & Ohio	31.2
Iron Ore Lines	
Duluth, Missabe & Northern	45.1
Duluth & Iron Range	42.7
Interior Trunk Lines	
Pennsylvania Co.	26.5
Pittsburgh, Cin., Chic. & St. Louis	20.8
Lake Shore & Michigan Southern	20.3
Michigan Central	16.1
Cleveland, Cincinnati, Chicago & St. Louis	21.1
Grain Carriers	
Chicago, Burlington & Quincy	19.0
Chicago & North Western	18.4
Chicago Great Western	18.3
Chicago, Milwaukee & St. Paul	16.6
Chicago, Rock Island & Pacific	16.0
Southern Trunk Lines	
Southern	19.0
Atlantic Coast Line	19.0
Seaboard Air Line	19.0
Louisville & Nashville	20.6
Illinois Central	20.1
Mobile & Ohio	17.0
Transcontinental Lines	
Great Northern	22.4
Northern Pacific	19.7
Southern Pacific	17.5
Union Pacific	16.3
Atchison, Topeka & Santa Fe	15.6

XVII. Loaded and Empty Freight Car Mileage

Roads in U. S. with over 100,000,000 car-miles. Figures given in millions of car-miles

EASTERN DISTRICT

Road	Loaded	Empty	Total	Per Cent. Empty
Pennsylvania	789	431	1220	35.24
N. Y. Central	577	287	864	33.26
Balt. & Ohio	519	280	799	36.28
L. S. & M. S.	293	148	441	38.56
Erie	299	125	424	29.48
Pennsylvania Co.	293	125	418	29.90
Mich. Central	293	91	384	23.69
Lehigh Valley	216	107	323	33.12
Phila. & Reading	193	116	309	37.54
P. C. C. & St. L.	202	104	306	33.98
C. C. C. & St. L.	196	101	297	34.00
Wabash	179	85	264	32.57
D. L. & W.	179	74	253	29.24
Boston & Maine	166	57	223	25.56
N. Y., N. H. & H.	147	59	206	28.64
Del. & Hudson	111	59	170	34.70
N. Y. C. & St. L.	107	48	155	30.96
C. of N. J.	86	54	140	38.57
Pere Marquette	93	38	131	29.00
Chi. & E. Ill.	81	48	129	37.20
Phila. W. & B.	67	33	100	33.00

SOUTHERN DISTRICT

Road	Loaded	Empty	Total	Per Cent. Empty
Ill. Central	387	186	573	32.46
N. & W.	289	194	483	40.17
Southern	302	124	426	29.10
L. & N.	270	136	406	33.49
C. & O.	228	135	363	37.19
A. C. L.	158	77	235	32.76
S. A. L.	105	47	152	30.92
M. & O.	91	35	126	27.77

WESTERN DISTRICT

Road	Loaded	Empty	Total	Per Cent. Empty
C. M. & St. P.	489	198	687	28.80
C. B. & Q.	451	212	663	31.97
A. T. & S. F.	374	147	521	28.23
C. & N. W.	337	163	500	32.60
Gt. Northern	308	131	439	29.82
C. R. I. & P.	309	126	435	29.19
No. Pac.	286	97	383	25.06
So. Pac.	268	113	381	29.65
Un. Pac.	231	84	315	26.66
St. L. I. M. & S.	169	76	245	31.02
S. C. L. & S. F.	163	76	239	31.79
M. St. P. & S. S. M.	149	51	200	25.50
Mo. Pac.	136	60	196	30.61
M. K. & T.	123	66	189	34.92
Texas & Pac.	83	37	120	30.83
Chi. & Alton	71	39	110	32.72
Chi. Gt. W.	73	30	103	29.12

XVIII. Transportation Statistics — 1914

Based on Interstate Commerce Commission Reports

Class I. Roads with annual operating revenues over $1,000,000

District	Eastern	Southern	Western	United States
Tons	1,105,436,517	256,515,825	481,263,714	1,843,216,056
Ton-miles	143,115,920,993	49,523,944,071	92,284,883,754	284,924,748,818
Locomotives				
Freight	17,053	5,923	14,429	37,405
Passenger	6,618	1,806	5,666	14,090
Switching	4,926	1,422	3,533	9,881
Unclassified	208	848	101	1,157
Total	28,805	9,999	23,729	62,335
Percentage				
Freight	59.2	59	60.8	59.8
Passenger	25.0	18	23.9	22.6
Switching	15.1	14	14.9	15.8
Unclassified	0.7	9	0.4	1.8
	46	16	38	100
Mileage				
Freight	308,922,938	130,293,576	239,560,170	678,776,684
Passenger	254,408,624	94,709,044	252,204,838	601,322,506
Switching	179,070,322	48,963,643	101,185,085	329,219,050
Unclassified	6,079,788	4,908,743	19,149,927	30,138,458
Total	748,481,672	278,875,006	612,100,020	1,639,456,698
Percentage				
Freight	41.2	46.7	39.2	41.4
Passenger	34.1	34.0	41.3	36.7
Switching	23.9	17.5	16.5	20.1
Unclassified	0.8	1.8	3.0	1.8
Car Miles				
Loaded	6,134,262,005	2,330,028,228	5.042,977,428	13,507,267,661
Empty	3,085,076,823	1,175,302,043	2,165,799,397	6,426,178,263
Total	9,219,338,828	3,505,330,271	7,208,776,825	19,933,445,924
Percentage				
Loaded	66	66	70	68
Empty	34	34	30	32

XVIII. Transportation Statistics — *Continued*

District	Eastern	Southern	Western	United States
Train miles				
Freight	257,418,781	116,699,422	216,715,704	590,833,907
Passenger	246,269,247	92,209,877	242,313,090	580,792,214
Switching	179,070,322	48,963,643	101,185,085	329,219,050
Total . . .	682,758,350	257,872,942	560,213,879	1,500,845,171
Percentage				
Freight	38	45	39	39
Passenger	36	36	43	38.7
Switching	26	19	18	22.3
Proportion				
Freight to				
Passenger . . .	100 to 95	100 to 70	100 to 114	100 to 97
Switching . . .	100 to 70	100 to 42	100 to 47	100 to 56
Cars per Train				
Loaded	23.8	20	23.2	22.9
Empty	12.0	10	10.0	10.9
Total . . .	35.8	30	33.2	33.8
Average car-load tons	23.4	21.3	18.4	21.1
Average train-load tons	557	427	427	483
Average haul-miles	129.47	193.06	191.76	154.58
Number of passengers	608,647,324	121,873,344	271,829,717	1,002,350,385
Passenger miles . .	16,348,655,263	4,585,239,471	13,633,090,680	34,566,985,414
Average journey, miles	26.86	37.62	50.15	34.49
Average number of passengers per train	66	49	56	59
Line-mileage . . .	58,667	42,055	126,277	226,999
Trains				
Per mile:				
Freight . . .	4,385	2,778	1,720	2,603
Passenger . . .	4,195	2,195	1,923	2,558
Total . . .	8,580	4,973	3,643	5,161
Switching . . .	3,051	1,165	803	1,450
Average trains per day:				
Freight . . .	12	7.6	4.7	7.1
Passenger . . .	11.5	6.0	5.3	7.0
Total . . .	23.5	13.6	10.0	14.1

Mixed trains excluded.
Equivalent switching mileage estimated at 6 miles an hour.
The average haul and journey are only over each road.

XIX. Special Statistics

Tons and Ton-miles. Passengers and Passenger-miles. Train-miles and Car-miles given in thousands

EASTERN DISTRICT

Railroad	Boston & Maine	New York New Haven & Hartford	Pennsylvania	New York Central & Hudson R.	Baltimore & Ohio	Erie
Tons freight	24,752	24,996	135,054	51,198	69,382	37,282
Ton-miles	2,635,138	2,294,783	22,174,791	10,420,847	13,425,552	6,408,667
Freight train-miles	8,142	7,378	30,272	20,352	21,238	10,714
Passenger " "	11,569	16,468	29,303	26,521	16,687	9,075
Switching " "	6,498	5,198	25,366	15,359	12,804	6,652
Total	26,209	29,044	84,941	62,232	50,729	26,441
Freight per cent.	31	25	36	33	42	41
Passenger " "	44	57	34	42	33	25
Switching " "	25	18	30	25	25	34
Car-miles loaded	166,211	147,591	789,095	579,772	519,949	299,397
" " empty	57,242	59,056	431,272	287,123	280,862	125,596
Total	223,453	206,647	1,220,367	866,895	800,811	424,993
Per cent. loaded	70	71	65	67	65	70
" " empty	30	29	35	33	35	30
Loaded cars per train	20	20	26	28	25	28
Empty " " "	7	8	14	14	13	12
Total	27	28	40	42	38	40
Average car-load, tons	15.8	15.5	28.2	18.3	25.3	21.4
" train- " "	323.	311.	732.	512.	632.	598.
" haul, miles	106.46	91.8	164.19	203.54	193.50	171.89
Number of passengers	47,032	87,183	78,174	53,699	22,718	26,977
Passenger-miles	896,081	1,600,476	1,967,004	1,983,885	826,672	611,436
Average journey, miles	19.05	18.36	25.16	36.94	36.39	22.66
" passengers per train	77	98	67	71	49	67
Line-mileage	2,302	2,003	4,084	3,756	4,478	1,988
Mileage per mile of line:						
Freight train	3,537	3,689	7,414	5,419	4,743	5,389
Passenger "	5,025	8,234	6,211	7,064	3,726	4,565
Total	8,562	11,923	13,625	12,483	8,469	9,954
Switching train	2,823	2,594	7,175	4,089	2,882	3,346
Average number trains per day:						
Freight	9.7	10.1	20.5	14.8	13.0	14.5
Passenger	13.8	22.6	16.9	19.3	10.2	12.5
Total	23.5	32.7	37.4	34.1	23.2	27.0
Ratio to line-mileage:						
Average haul	0.046	0.045	0.040	0.054	0.043	0.086
Average journey	0.0083	0.0091	0.0061	0.0098	0.0081	0.011

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT — *Continued*

Railroads	Pennsylvania Co.	Pittsburgh Cin., Chicago & St. Louis	Vandalia	Lake Shore & Michigan Southern	Michigan Central	New York, Chicago & St. Louis
Tons freight	100,589	39,356	10,404	38,139	20,398	8,628
Ton-miles	7,782,640	4,638,057	1,160,723	5,968,918	3,213,287	1,884,451
Freight train-miles	13,207	9,757	2,990	8,719	6,625	5,468
Passenger " "	9,613	6,107	1,674	9,984	6,778	1,192
Switching " "	10,398	8,292	2,816	8,497	6,947	1,949
Total	33,218	24,156	7,480	27,200	20,350	8,609
Freight per cent.	40	41	40	32	32	63
Passenger " "	31	34	38	37	34	14
Switching " "	29	25	22	31	34	23
Car-miles loaded	293,124	222,444	56,350	293,231	193,954	107,754
" " empty	125,835	104,429	26,504	148,547	91,476	48,285
Total	418,959	326,873	82,854	441,778	285,430	156,039
Per cent. loaded	70	68	68	66	68	69
" " empty	30	32	32	34	32	31
Loaded cars per train	22	23	19	34	29	20
Empty " " "	9	10	9	17	14	8
Total	31	33	28	51	43	28
Average car-load, tons	26.5	20.8	20.5	20.3	16.1	17.5
" train- " "	589.	475.	388.	684.	472.	350.
" haul, miles	77.37	117.85	111.56	156.50	157.52	218.40
Number of passengers	14,943	11,674	3,094	10,197	6,252	887
Passenger-miles	573,947	455,871	116,932	669,692	450,157	102,167
Average journey, miles	34.39	38.75	37.79	65.67	71.99	115.06
" passengers per train	53	74	70	67	66	86
Line-mileage	1,749	1,472	910	1,853	1,780	567
Mileage per mile of line						
Freight train	7,551	6,628	3,287	4,705	3,722	9,679
Passenger "	5,496	4,148	1,840	5,393	3,808	2,102
Total	13,047	10,776	5,127	10,098	7,530	11,781
Switching train	5,945	5,633	3,095	4,575	3,902	3,437
Average number trains per day:						
Freight	20.7	19.2	9.0	12.9	10.2	26.5
Passenger	15.0	11.4	5.0	14.8	10.4	6.0
Total	35.7	30.6	14.0	27.7	20.6	32.5
Ratio to line-mileage:						
Average haul	0.044	0.080	0.122	0.084	0.088	0.385
Average journey	0.019	0.026	0.041	0.035	0.040	0.202

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT — *Continued*

Railroad	Wabash	Cleveland, Cincinnati, Chicago & St. Louis	Cincinnati, Hamilton & Dayton	Pere Marquette	Grand Rapids & Indiana	Chicago Indianapolis & Louisville
Tons freight	14,260	25,430	11,986	10,867	4,855	4,652
Ton-miles	3,321,617	4,148,299	1,476,238	1,808,504	466,230	631,553
Freight train-miles	8,312	8,144	2,244	3,888	1,405	1,449
Passenger " "	7,333	7,966	2,091	2,860	1,530	1,727
Switching " "	3,907	6,512	2.132	3,681	675	740
Total	19,552	22,622	6,467	10,429	3,610	3,916
Freight per cent.	43	36	34	37	39	37
Passenger " "	37	35	32.5	35	43	44
Switching " "	20	29	33.5	28	18	19
Car-miles loaded	179,360	196,621	51,655	93,993	24,053	31,013
" " empty	85,698	101,954	26,874	38,282	9,265	14,497
Total	265,058	298,575	78,529	132,275	33,318	45,510
Per cent. loaded	67	66	66	71	73	68
" " empty	33	34	34	29	27	32
Loaded cars per train	21	24	23	24	17	21
Empty " " "	11	12	12	10	7	10
Total	32	36	35	34	24	31
Average car-load, tons	18.9	21.1	28.6	19.4	19.6	20.7
" train- " "	400.	509.	658.	465.	333.	436.
" haul, miles	232.92	163.12	123.16	166.42	96.01	135.74
Number of passengers	6,073	8,268	2,739	5,569	2,796	2,245
Passenger-miles	381,382	453,692	96,869	206,954	94,676	92,595
Average journey, miles	62.79	54.87	35.36	37.16	33.86	41.24
" passengers per train	52	57	46	72	65	54
Line-mileage	2,514	2,361	1,015	2,322	575	618
Mileage per mile of line:						
Freight train	3,324	3,451	2,207	1,674	2,443	2,344
Passenger "	2,933	3,375	2,030	1,227	2,661	2,794
Total	6,257	6,826	4,237	2,901	5,104	5,138
Switching train	1,562	2,759	2,100	1,586	1,174	1,197
Average number trains per day:						
Freight	9.1	9.5	6.0	4.6	6.7	6.4
Passenger	8.0	9.2	5.6	3.4	7.3	7.7
Total	17.1	18.7	11.6	8.0	14.0	14.1
Ratio to line-mileage:						
Average haul	0.042	0.069	0.121	0.071	0.167	0.219
Average journey	0.025	0.023	0.035	0.016	0.059	0.067

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT — *Continued*

Railroad	Philadelphia & Reading	Lehigh Valley	Central R.R. of New Jersey	Delaware, Lackawanna, & Western	Delaware & Hudson	Buffalo, Rochester & Pittsburgh
Tons freight	54,207	29,924	32,596	23,434	19,976	12,295
Ton-miles	5,505,255	5,218,751	2,372,954	4,081,165	2,870,361	1,980,012
Freight train-miles	9,292	8,653	4,205	6,162	5,341	2,816
Passenger " "	6,735	4,562	3,524	6,167	2,793	1,366
Switching " "	6,365	5,364	4,724	4,328	2,638	1,327
Total	22,392	18,579	12,453	16,657	10,772	5,509
Freight per cent.	42	47	33	37	50	51
Passenger " "	30	29	29	37	26	24
Switching " "	28	24	38	26	24	25
Car-miles loaded	193,460	216,682	86,051	179,059	111,907	55,400
" " empty	116,630	107,877	54,396	74,129	59,900	36,955
Total	310,090	324,559	140,447	253,188	171,807	92,355
Per cent. loaded	62	67	61	70	65	60
" " empty	38	33	39	30	35	40
Loaded cars per train	21	25	20	29	21	20
Empty " " "	12	12	13	12	11	13
Total	33	37	33	41	32	33
Average car-load, tons	28.4	24.0	28.0	23.3	25.6	36.7
" train- " "	592.	603.	564.	662.	537.	703.
" haul, miles	101.56	174.40	72.80	174.15	143.69	161.04
Number of passengers	26,834	5,729	24,869	25,372	9,154	2,059
Passenger-miles	406,744	265,337	377,968	544,624	151,470	55,632
Average journey, miles	15.16	46.31	15.20	21.47	16.55	27.01
" passengers per train	60.	58.	107.	88.	54.	41.
Line-mileage	1,120	1,444	678	960	880	586
Mileage per mile of line:						
Freight train	8,297	5,992	6,202	6,419	6,070	4,805
Passenger "	6,013	3,159	6,967	4,508	2,998	2,331
Total	14,310	9,151	13,169	10,927	8,068	7,136
Switching train	5,630	3,722	5,197	6,424	3,180	2,264
Average number trains per day:						
Freight	22.7	16.4	17.0	17.6	16.6	13.2
Passenger	16.5	8.6	19.1	12.4	8.2	6.4
Total	39.2	25.0	36.1	30.0	24.8	19.6
Ratio to line-mileage:						
Average haul	0.090	0.129	0.107	0.181	0.163	0.275
Average journey	0.014	0.032	0.022	0.022	0.019	0.046

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT — *Continued*

Railroad	Northern Central	Bessemer & Lake Erie	Pittsburgh & Lake Erie	Wheeling & Lake Erie	Hocking Valley	Western Maryland
Tons freight	22,180	14,872	32,068	12,076	10,487	10,979
Ton-miles	1,632,418	1,750,283	2,022,080	1,192,862	1,315,425	1,241,476
Freight train-miles	2,933	1,636	1,739	1,566	1,294	2,120
Passenger " "	2,374	499	1,452	905	848	1,369
Switching " "	1,585	805	3,149	1,625	1,339	1,303
Total	6,892	2,940	6,340	4,096	3,481	4,792
Freight per cent.	43	56	27	38	37	44
Passenger " "	34	17	23	22	25	29
Switching " "	23	27	50	40	38	27
Car-miles loaded	64,771	38,734	57,967	35,224	35,629	39,433
" " empty	28,395	21,522	34,618	17,597	26,513	25,660
Total	93,166	60,256	92,585	52,821	62,142	65,593
Per cent. loaded	70	64	63	67	57	61
" " empty	30	36	37	33	43	39
Loaded cars per train	22	24	33	23	28	19
Empty " " "	9	13	20	11	20	12
Total	31	37	53	34	48	31
Average car-load, tons	25.2	44.7	35	33.2	36.4	31.1
" train- " "	551.	1,072.	1,162.	762.	1,017.	586.
" haul, miles	73.60	117.69	63.06	98.77	125.43	113.08
Number of passengers	5,174	1,138	4,842	1,789	2,156	2,210
Passenger-miles	125,304	23,434	96,473	40,257	49,193	54,454
Average journey, miles	24.22	20.59	19.92	22.50	29.26	24.63
" passengers per train	54	47	66	44	58	40
Line-mileage	472	213	224	543	351	661
Mileage per mile of line:						
Freight train	6,214	7,680	7,760	2,884	3,687	3,343
Passenger "	5,030	2,343	6,483	1,666	2,420	2,071
Total	11,244	10,023	14,243	4,550	6,107	5,414
Switching train						
Average number trains per day:						
Freight	17.0	21.1	21.3	7.9	10.1	9.1
Passenger	13.8	6.4	17.8	4.5	6.6	5.7
Total	30.8	27.5	39.1	12.4	16.7	14.8
Ratio to line-mileage						
Average haul	0.157	0.556	0.281	0.182	0.357	0.173
Average journey	0.051	0.097	0.089	0.041	0.083	0.037

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT — *Continued*

Railroad	Chicago & Eastern Illinois	Elgin, Joliet & Eastern	Philadelphia, Baltimore, & Washington	Long Island	West Jersey & Seashore	Atlantic City
Tons freight	13,803	25,193	15,695	4,292	2,952	1,429
Ton-miles	2,212,684	1,593,568	1,220,630	95,175	98,625	34,070
Freight train-miles	3,652	1,942	3,381	539	513	241
Passenger " "	3,188		6,131	5,477	3,122	1,268
Switching " "	2,310	3,408	1,647	658	271	265
Total	9,150	5,350	11,159	6,674	3,906	1,774
Freight per cent.	40	36	30	8	13	14
Passenger " "	35		55	82	80	71
Switching " "	25	64	15	10	7	15
Car-miles loaded	81,985	46,397	67,340	6,364	6,130	2,567
" " empty	48,437	27,467	33,498	3,083	2,591	940
Total	130,422	73,864	100,838	9,447	8,721	3,507
Per cent. loaded	63	63	67	68	70	73
" " empty	37	37	33	32	30	27
Loaded cars per train	22	24	20	12	12	11
Empty " " "	14	14	10	6	5	4
Total	36	38	30	18	17	15
Average car-load, tons	27.5	34.3	18.	15.	16.	13.2
" train- " "	606.	821.	360.	176.	192.	141.
" haul, miles	160.30	63.25	77.77	22.17	33.40	23.83
Number of passengers	5,149	—	13,543	41,570	10,857	3,718
Passenger-miles	166,516	—	435,881	602,787	297,506	126,706
Average journey, miles	32.34	—	32.18	14.50	27.40	34.08
" passengers per train	52	—	71.	110.	95.	100.
Line-mileage	1,282	809	717	398	356	170
Mileage per mile of line:						
Freight train	2,850	2,400	4,574	1,355	1,410	1,418
Passenger "	2,487	—	8,555	13,761	8,770	7,459
Total	5,437	2,400	13,129	15,116	10,180	8,877
Switching train	1,802	4,212	2,277	1,653	761	1,559
Average number trains per day:						
Freight	7.8	6.6	12.5	3.7	3.9	4.0
Passenger	6.8	—	23.7	37.7	24.0	20.4
Total	14.6	6.6	36.2	41.4	27.9	24.4
Ratio to line-mileage:						
Average haul	0.125	0.077	0.108	0.055	0.094	0.152
Average journey	0.023	—	0.045	0.036	0.076	0.200

XIX. Special Statistics — *Continued.* Comparative Performance

Train-miles and Car-miles given in Thousands

EASTERN DISTRICT

	General Average	Special Maxima and Minima			
Number of Roads	74	36	49 per cent.		
Line-mileage	58,667	48,211	82 per cent.		
		Maxima		Minima	
		Road		Road	
Tons of freight	1,105,436	Pennsylvania	135,054	Atlantic City	1,429
Ton-miles	143,115,920	"	22,174,791	"	39,070
Freight train-miles	308,922	"	30,272	"	241
Passenger " "	254,408	"	29,303	Bessemer & L. Erie	499
Switching " "	179,070	"	25,366	Atlantic City	265
Total	742,400	"	84,941	"	1,774
Freight-miles per cent.	37	N. Y. Chi. & St. Louis	63	Long Island	8
Passenger " " "	31	Long Island	82	N. Y., Chi. & St. Louis	14
Switching " " "	32	Wheeling & L. Erie	69	W. Jersey & Sea Shore	7
Car-miles loaded	6,134,262	Pennsylvania	789,095	Atlantic City	2,567
" " empty	3,085,076	"	431,272	"	940
Total	9,219,338	"	1,210,367	"	3,507
Per cent. loaded	66	Gr. Rapids & Indiana	73	Hocking Valley	57
" " empty	34	Hocking valley	43	Gr. Rapids & Indiana	27
Loaded cars per train	23.8	L. Shore & Mich. So.	34	Atlantic City	11
Empty " " "	12.0	" "	17	"	4
Total	35.8	" "	51	"	15
Average car-load, tons	23.4	Bessemer & L. Erie	44.7	"	13.2
" train- " "	557.	Pittsburgh & L. Erie	1162.	"	141.
" haul, miles	129.47	Wabash	232.92	Long Island	22.17
Number of passengers	608,647	N.Y., N. H. & Hartford	87,183	N. Y., Chi. & St. Louis	887
Passenger-miles	16,348,665	N. Y. C. & Hudson Riv.	1,983,885	Bessemer & L. Erie	23,434
Average journey, miles	26.86	N. Y., Chi. & St. Louis	115.06	Phila. & Reading	15.16
" passengers per train	66.	Long Island	110.	West'n Maryland	40.
Line-mileage		Baltimore & Ohio	4,478	Atlantic City	170.
Mileage per mile of line:					
Freight train	4,385	N. Y., Chi. & St. Louis	9,679	Long Island	1,355
Passenger "	4,195	Phila. & Reading	8,297	Pere Marquette	1,227
Total	8,580	" "	14,380	Elgin, Joliet & East'n	2,400
Switching train	3,051	Pittsburgh & L. Erie	14,068	W. Jersey & Sea Shore	761
Average number trains per day:					
Freight	12	N. Y., Chi. & St. Louis	26.5	Long Island	3.7
Passenger	11.5	Long Island	37.7	Pere Marquette	3.4
Total	23.5	" "	41.4	"	8.0
Ratio to line-mileage:					
Average haul		Bessemer & L. Erie	0.535	Pennsylvania	0.040
Average journey		N. Y., Chi. & St. Louis	0.202	"	0.0061

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

SOUTHERN DISTRICT

Railroad	Norfolk & Western	Chesa-peake & Ohio	Virginian	Southern	Atlantic Coast Line	Seaboard Air Line
Tons freight	34,000	27,772	4,776	29,650	13,114	10,410
Ton-miles	9,155,506	7,064,650	1,694,615	4,584,338	2,040,571	1,575,008
Freight train-miles	11,216	8,092	1,202	15,755	8,516	5,664
Passenger " "	4,212	5,202	561	18,363	8,563	6,019
Switching " "	3,390	5,091	282	7,640	3,994	2,233
Total	18,818	18,385	2,045	41,758	21,073	13,916
Freight per cent.	59.5	44	59	38	40	41
Passenger " "	22.4	28	27	44	40	43
Switching " "	18.1	28	14	18	20	16
Car-miles, loaded	289,721	228,285	36,789	302,866	158,020	105,207
" " empty	194,094	135,488	32,297	124,740	77,621	47,253
Total	483,815	363,773	69,086	427,606	235,641	152,460
Per cent., loaded	60	62	53	71	67	69
" " empty	40	38	47	29	33	31
Loaded cars per train	26	28	31	19	19	19
Empty " " "	17	17	26	8	8	8
Total	43	45	57	27	27	27
Average car-load, tons	31.6	31.2	45.5	15.7	12.9	14.6
" train- " "	817.	873.	1,409.	299.	240.	278.
" haul, miles	269.28	254.84	354.77	154.61	155.59	151.28
Number of passengers	6,269	6,491	658	19,634	9,153	5,146
Passenger-miles	229,755	295,653	15,157	888,312	417,417	247,690
Average journey miles	36.65	44.93	23.01	45.24	45.60	48.13
" passengers per train	54.	56.	27.	46.	49.	41.
Line-mileage	2,036	2,346	503	7,033	4,646	3,084
Mileage per mile of line:						
Freight train	5,509	3,449	1,827	2,240	1,833	1,837
Passenger "	2,069	2,217	853	2,611	1,843	1,952
Total	7,578	5,666	2,680	4,851	3,676	3,789
Switching train	1,665	2,170	429	1,085	860	726
Average number trains per day:						
Freight	16.7	9.5	5.0	6.1	5.0	5.0
Passenger	5.7	6.1	2.4	7.2	5.1	5.3
Total	22.4	15.6	7.4	13.3	10.1	10.3
Ratio to line-mileage:						
Average haul	0.132	0.108	0.705	0.022	0.035	0.049
Average journey	0.017	0.019	0.045	0.006	0.009	0.015

XIX. Special Statistics—*Continued*

Train-miles and Car-miles given in Thousands

SOUTHERN DISTRICT — *Continued*

Railroad	Richmond, Fredericksburg & Potomac	Central of Georgia	Atlanta, Birmingham & Atlantic	Carolina, Clinchfield & Ohio	Atlanta & West Point	Florida East Coast
Tons freight	1,246	5,631	1,994	2,623	776	910
Ton-miles	153,946	847,005	314,778	403,010	45,212	149,920
Freight train-miles	595	2,847	1,194	331	192	947
Passenger " "	770	3,735	608	251	376	1,226
Switching " "	368	1,287	657	106	15	379
Total	1,733	7,869	2,459	688	583	2,552
Freight per cent.	34	36	49	48	33	37
Passenger " "	45	48	24	36	64	48
Switching " "	21	16	27	16	3	15
Car-miles, loaded	10,799	55,425	18,982	10,522	3,487	16,115
" " empty	6,338	23,615	10,601	8,232	1,077	10,613
Total	17,137	79,040	29,583	18,754	4,564	26,728
Per cent., loaded	63	70	64	56	76	60
" " empty	37	30	36	44	24	40
Loaded cars per train	18	19	16	32	18.2	17
Empty " " "	11	9	9	24	5.6	11
Total	29	28	25	56	23.8	28
Average car-load, tons	14.2	15.7	19.22	38.4	13.0	9.3
" train- " "	257.	298.	307.	1,202.	234.	158.
" haul, miles	69.27	150.41	182.91	153.61	58.20	164.16
Number of passengers	961	5,333	918	393	610	1,482
Passenger-miles	44,578	181,675	30,422	9,684	23,952	78,075
Average journey, miles	46.37	34.06	33.13	24.58	39.27	51.32
" passengers per train	58.	49.	50.	38.	64.	62.
Line-mileage	88	1,924	646	248	93	685
Mileage per mile of line:						
Freight train	6,761	1,480	1,850	1,335	2,065	1,385
Passenger "	8,756	1,941	924	1,012	4,043	1,800
Total	15,517	3,421	2,774	2,347	6,108	3,185
Switching train	4,068	669	1,017	428	161	553
Average number trains per day:						
Freight	18.5	4.0	5.0	3.7	8.1	3.8
Passenger	24.0	5.3	2.5	2.8	11.0	5.0
Total	42.5	9.3	7.5	6.5	19.1	8.8
Ratio to line-mileage:						
Average haul	0.787	0.078	0.283	0.619	0.625	0.239
Average journey	0.527	0.017	0.051	0.099	0.422	0.074

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

SOUTHERN DISTRICT — *Continued*

Railroad	Illinois Central	Yazoo & Mississippi Valley	Louisville & Nashville	Nashville, Chattanooga & St. Louis	Mobile & Ohio	Cincinnati, New Orleans & Texas Pacific
Tons freight	32,342	6,885	32,215	5,534	7,111	5,373
Ton-miles	7,789,173	1,171,363	5,511,812	883,220	1,598,623	1,102,522
Freight train-miles	18,395	2,813	17,996	3,948	4,806	2,682
Passenger " "	13,180	2,154	10,647	2,752	1,898	1,768
Switching " "	7,430	1,235	6,307	1,319	1,395	908
Total	39,005	6,202	34,950	8,019	8,099	5,358
Freight per cent.	47	45	52	49	60	50
Passenger " "	34	35	30	34	23	33
Switching " "	19	20	18	17	17	17
Car-miles, loaded	387,428	59,514	270,769	55,417	91,961	63,750
" " empty	186,568	20,644	136,313	24,195	35,466	23,223
Total	573,996	80,158	407,082	79,612	127,427	86,973
Per cent., loaded	68	74	66	70	72	73
" " empty	32	26	34	30	28	27
Loaded cars per train	21	20	15	14	19	24
Empty " " "	10	7	7	6	7	8
Total	31	27	22	20	26	32
Average car-load, tons	20.1	19.2	20.6	14.02	17.08	17.1
" train- " "	423.	354.	309.	199.	323.	411.
" haul, miles	240.83	170.12	171.09	150.56	229.86	205.19
Number of passengers	27,522	4,062	13,360	3,283	2,202	1,513
Passenger-miles	718,962	113,918	577,420	137,958	69,057	96,885
Average journey, miles	26.12	28.04	43.22	42.02	31.36	64.04
" passengers per train	54	53	54	50	37	55
Line-mileage	4,767	1,372	4,937	1,230	1,122	337
Mileage per mile of line:						
Freight train	3,859	2,050	3,645	3,210	4,283	7,959
Passenger "	2,765	1,570	2,156	2,238	1,700	5,256
Total	6,624	3,620	5,801	5,448	5,983	13,215
Switching train	1,567	900	1,075	1,024	1,243	2,654
Average number trains per day:				9		
Freight	10.6	5.6	10	6.1	11.7	21.8
Passenger	7.6	4.3	6	15.1	4.4	19.4
Total	18.2	9.9	16		16.1	36.2
Ratio to line-mileage:						
Average haul	0.050	0.124	0.034	0.122	0.200	0.609
Average journey	0.005	0.020	0.008	0.034	0.028	0.190

XIX. Special Statistics — *Continued.* Comparative Performance

Train-miles and Car-miles given in Thousands

SOUTHERN DISTRICT

	General Average	Special Maxima and Minima			
Number of Roads	36	18	50 per cent.		
Line-mileage	42,055	37,097	88 per cent.		
		Maxima		**Minima**	
		Road		Road	
Tons of freight	256,515	Norfolk & West'n	34,000	Atlanta & West Point	776
Ton-miles	49,523,994	" "	9,155,506	" " "	45,212
Freight train-miles	116,699	Illinois Central	18,395	" " "	192
Passenger " "	92,210	Southern	18,363	Carolina, Clinchfield & Ohio	251
Switching " "	48,963	"	7,640	Atlanta & West Point	15
Total	257,872	"	41,758	" " "	583
Freight per cent.	45	Mobile & Ohio	60	" " "	33
Passenger " "	36	Atlanta & West Point	64	Norfolk & Western	22.4
Switching " "	19	Chesapeake & Ohio	28	Atlanta & West Point	3
Car-miles, loaded	2,330,028	Illinois Central	387,428	" " "	3,487
" " empty	1,175,302	Norfolk & Western	190,094	" " "	1,077
Total	3,505,330	Illinois Central	513,996	" " "	4,564
Per cent., loaded	66	Atlanta and West Point	76	Virginian	53
" " empty	34	Virginian	47	Atlanta & West Point	24
Loaded cars per train	20	Carolina, Clinchfield & Ohio	32	Nashv. Chatt'a & St. L.	14
Empty " " "	10	Virginian	26	Atlanta & West Point	5.6
Total	30	"	57	Nashv., Chatt'a & St. L.	20
Average car-load, tons	21.3	"	45.5	Florida East Coast	9.3
" train- " "	427	"	1409.	" " "	158
" haul, miles	193.06	"	354.77	Atlanta & West Point	58.20
Number of passengers	121,873	Illinois Central	27,522	Carolina, Cl'fd & Ohio	393
Passenger-miles	4,585,239	Southern	888,312	" " "	9,684
Average journey, miles	37.62	Cin., N. O. & Texas Pac.	64.04	Virginian	2,301
" passengers per train	49	Atlanta & West Point	64	"	27
Line-mileage	42,055	Southern	7,033	Rich., Fred'g & Pot.	88
Mileage per mile of line:					
Freight train	2,778	Cin., N. O. & Texas Pac.	7,959	Carolina, Cl'fd & Ohio	1,335
Passenger "	2,195	Richm'd, Fred'g & Pot.	8,756	Virginian	853
Total	4,973	" " "	15,031	Carolina, Cl'fd & Ohio	2,347
Switching train	1,165	" " "	4,068	Atlanta & West Point	161
Average number trains per day:					
Freight	7.6	Cin., N. O. & Tex. Pac.	21.8	Carolina, Cl'fd & Ohio	3.7
Passenger	6.0	Rich'd, Fred'g. & Pot.	24.0	Atlanta, Bir'm & Atl'c	2.5
Total	13.6	" " "	40.8	Carolina, Cl'fd & Ohio	6.5
Ratio to line-mileage:					
Average haul		" " "	0.787	Southern	0.022
Average journey		" " "	0.527	"	0.006

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT

Railroad	Chicago, Burlington, & Quincy	Chicago & North Western	Chicago, Rock Island, & Pacific	Chicago Great Western	Chicago, St. Paul, Minneapolis, & Omaha	Chicago & Alton
Tons freight	32,388	43,309	21,117	5,557	8,466	8,484
Ton-miles	8,612,629	6,229,944	4,940,743	1,369,026	1,294,143	1,464,671
Freight train-miles	17,066	16,140	15,447	2,763	3,529	3,288
Passenger " "	17,721	19,755	17,627	3,119	3,828	3,464
Switching " "	9,779	10,153	6,573	1,424	1,914	2,015
Total	44,566	46,048	39,647	7,306	9,271	8,767
Freight per cent.	38	35	39	38	38	38
Passenger " "	40	43	44	43	41	39
Switching " "	22	22	17	19	21	23
Car-miles, loaded	451,471	337,816	309,981	73,478	67,314	71,898
" " empty	212,332	163,633	126,875	30,524	28,879	39,747
Total	663,803	501,449	436,856	104,002	96,193	111,645
Per cent., loaded	68	67	71	71	70	64
" " empty	32	33	29	29	30	36
Loaded cars per train	27	21	20	27	16	22
Empty " " "	12	10	8	11	7	12
Total	39	31	28	38	23	34
Average car-load, tons	19.0	18.4	16	18.3	19.23	20.3
" train- " "	507.	386.	320.	495.	307.	446.
" haul, miles	265.91	143.85	233.96	245.42	152.85	245.42
Number of passengers	23,445	33,389	20,064	2,817	4,881	3,909
Passenger-miles	1,152,123	1,173,435	954,616	160,199	266,685	218,638
Average journey, miles	49.14	35.14	47.58	56.86	54.63	56.86
" passengers per train	65	60.	56	51	70	64
Line-mileage	9,140	8,071	7,730	1,496	1,748	1,033
Mileage per mile of line:						
Freight train	1,896	2,017	2,000	1,847	2,019	3,183
Passenger "	1,969	2,469	2,540	2,085	2,196	3,353
Total	3,865	4,486	4,540	3,932	4,215	6,636
Switching train	1,081	1,269	850	685	1,095	1,951
Average number trains per day:						
Freight	5.2	5.5	5.5	5.1	5.5	8.4
Passenger	5.4	6.8	7.	5.7	6.0	9.2
Total	10.6	12.3	12.5	10.8	11.5	17.6
Ratio to line-mileage:						
Average haul	0.029	0.011	0.030	0.164	0.087	0.237
Average journey	0.005	0.004	0.006	0.038	0.031	0.055

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	Minneapolis, St. Paul, & Sault Ste. Marie	Minneapolis & St. Louis	Duluth, South Shore, & Atlantic	Duluth, Missabe, & Northern	Duluth & Iron Range	Duluth, Winnipeg, & Pacific
Tons freight	12,980	5,582	3,216	12,465	11,218	2,005
Ton-miles	2,770,425	850,221	260,289	918,448	783,543	179,369
Freight train-miles	5,879	2,668	949	828	1,000	410
Passenger " "	5,307	1,996	934	385	258	249
Switching " "	2,207	831	273	346	426	270
Total	13,393	5,495	2,156	1,559	1,684	929
Freight per cent.	44	49	44	53	60	44
Passenger " "	40	36	43	25	15	26
Switching " "	16	15	13	22	25	30
Car-miles, loaded	149,538	46,124	13,148	20,300	18,451	7,119
" " empty	51,112	19,784	5,282	17,333	16,130	3,694
Total	200,650	65,908	18,430	37,633	34,581	10,813
Per cent., loaded	75	70	73	55	53	66
" " empty	25	30	27	45	47	34
Loaded cars per train	25	16	14	25	18	18
Empty " " "	9	7	5	20	16	9
Total	34	23	19	45	34	27
Average car-load, tons	18.8	18.43	19.8	45.1	42.7	24.21
" train- " "	471.	292.	269.	1108.	783.	420.
" haul, miles	213.43	152.30	80.93	73.68	69.83	85.94
Number of passengers	4,536	2,479	903	506	504	195
Passenger-miles	329,602	92,125	45,090	19,516	14,823	14,282
Average journey, miles	72.66	37.15	49.91	38.50	29.36	72.89
" passengers per train	62	47	48	51	58	58
Line-mileage	4,045	1,646	627	360	282	181
Mileage per mile of line:						
Freight train	1,469	1,621	1,513	2,300	3,546	2,210
Passenger "	1,326	1,212	1,490	1,070	915	1,375
Total	2,795	2,833	3,003	3,370	4,461	3,585
Switching train	551	514	450	961	1,511	1,492
Average number trains per day						
Freight	4.	4.4	4.1	6.3	9.7	6.5
Passenger	3.6	3.3	4.1	3.	2.5	3.5
Total	7.6	7.7	8.2	9.3	12.2	10.0
Ratio to line-mileage:						
Average haul	0.052	0.092	0.120	0.204	0.247	0.474
Average journey	0.018	0.022	0.080	0.107	0.104	0.402

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	St. Louis-San Francisco	Missouri Pacific	Missouri, Kansas & Texas	St. Louis, Iron Mountain & Southern	St. Louis South-western	Kansas City Southern
Tons freight	17,986	12,182	9,121	13,652	2,268	4,066
Ton-miles	2,910,096	2,388,847	1,850,591	3,116,024	622,985	1,062,756
Freight train-miles	9,192	6,899	6,687	6,207	1,469	2,070
Passenger " "	9,166	6,268	7,539	5,698	1,239	1,451
Switching " "	4,494	3,278	2,986	2,533	473	1,056
Total	22,852	16,445	17,212	14,438	3,181	4,577
Freight per cent.	40	42	39	43	46	45
Passenger " "	40	39	44	40	39	32
Switching " "	20	19	17	17	15	23
Car-miles, loaded	163,190	136,177	123,888	169,768	38,062	51,393
" " empty	76,525	60,730	66,204	67,063	16,040	20,994
Total	239,715	196,907	190,092	236,831	54,102	72,387
Per cent., loaded	64	70	65	72	70	79
" " empty	36	30	35	28	30	21
Loaded cars per train	18	20	18	27	25	25
Empty " " "	8	9	10	11	11	10
Total	26	29	28	38	36	35
Average car-load, tons	17.5	17.3	14.9	18.6	16.4	20.5
" train- " "	316.	346.	268.	503.	409.	513.
" haul, miles	161.79	196.10	202.88	228.23	274.67	261.38
Number of passengers	12,619	6,231	7,334	8,096	1,779	2,005
Passenger-miles	506,029	259,470	404,034	289,376	66,688	73,356
Average journey, miles	40.10	41.64	55.08	35.74	37.47	36.57
" passengers per train	55	41	54	51	54	51
Line-mileage	4,746	3,920	3,825	3,365	924	827
Mileage per mile of line:						
Freight train	1,937	1,758	1,748	1,844	1,590	2,455
Passenger "	1,931	1,597	1,971	1,693	1,341	1,633
Total	3,868	3,355	3,719	3,537	2,931	4,088
Switching train	947	836	781	753	514	1,277
Average number trains per day:						
Freight	5.3	4.8	4.8	5.0	4.4	6.7
Passenger	5.3	4.4	5.4	4.6	3.7	4.5
Total	10.6	9.2	10.2	9.6	8.1	11.2
Ratio to line-mileage:						
Average haul	0.034	0.050	0.052	0.068	0.292	0.316
Average journey	0.008	0.010	0.014	0.010	0.040	0.044

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	Texas & Pacific	Gulf, Colorado & Santa Fé	Galveston, Harrisburg & San Antonio	International & Great Northern	Houston & Texas Central	El Paso & South Western
Tons freight	7,019	4,282	4,251	3,556	2,505	4,540
Ton-miles	1,311,948	986,679	1,047,968	580,827	378,165	789,550
Freight train-miles	5,184	2,762	2,458	2,506	1,279	1,828
Passenger " "	3,764	2,285	2,218	1,735	1,395	1,246
Switching " "	1,847	783	782	731	692	574
Total	10,795	5,830	5,458	4,972	3,366	3,648
Freight per cent.	49	47	45	50	38	50
Passenger " "	34	39	41	35	41	34
Switching " "	17	14	14	15	21	16
Car-miles, loaded	83,531	63,663	54,181	42,711	21,974	34,771
" " empty	37,817	26,645	19,025	22,885	9,603	21,114
Total	121,348	90,308	73,206	65,596	31,577	55,885
Per cent., loaded	70	71	74	64	70	62
" " empty	30	29	26	36	30	38
Loaded cars per train	16	21	22	16	15	16
Empty " " "	7	9	8	9	7	10
Total	23	30	30	25	22	26
Averge car-load, tons	15.8	15.5	19.4	13.6	17.21	22.71
" train- " "	253.	324.	427.	215.	259.	365.
" haul, miles	186.91	230.	246.48	163.32	150.95	173.90
Number of passengers	3,598	2,785	1,743	2,009	1,424	335
Passenger-miles	190,346	130,910	154,492	90,078	74,749	38,421
Average journey, miles	52.89	46.99	88.59	44.82	54.59	114.51
" passengers per train	51	57	70	51	56	31
Line-mileage	1,885	1,596	1,338	1,160	813	1,001
Mileage per mile of line:						
Freight train	2,750	1,730	1,837	2,160	1,573	1,828
Passenger "	2,000	1,431	1,657	1,496	1,716	1,246
Total	4,750	3,161	3,494	3,656	3,289	3,074
Switching train	980	490	585	630	851	574
Average number trains per day:						
Freight	7.5	4.5	5.0	6.0	4.7	5.0
Passenger	5.5	4.0	4.3	4.1	4.3	3.4
Total	13.0	8.5	9.3	10.1	9.0	8.4
Ratio to line-mileage:						
Average haul	0.099	0.144	0.184	0.146	0.185	0.173
Average journey	0.028	0.029	0.066	0.039	0.067	0.114

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	Atchison, Topeka & Santa Fé	Southern Pacific	Union Pacific	Chicago, Milwaukee & St. Paul	Great Northern	Northern Pacific
Tons freight	21,540	20,338	10,236	33,007	30,867	20,422
Ton-miles	5,893,379	4,726,481	3,801,268	8,079,689	6,930,295	5,629,351
Freight train-miles	14,165	10,045	7,736	19,700	9,680	9,189
Passenger " "	18,512	20,968	10,150	17,567	12,475	12,015
Switching " "	6,305	4,705	2,351	10,514	4,110	5,084
Total	38,982	35,718	20,237	47,781	26,265	26,288
Freight per cent.	36	28	39	41	37	35
Passenger " "	48	59	50	37	47	46
Switching " "	16	13	11	22	16	19
Car-miles, loaded	374,218	268,829	231,804	489,450	308,809	286,684
" " empty	147,088	113,180	84,958	198,240	131,955	97,357
Total	521,306	382,009	316,762	687,690	440,764	384,041
Per cent., loaded	72	70	73	71	70	75
" " empty	28	30	27	29	30	25
Loaded cars per train	27	27	30	25	32	31
Empty " " "	10	11	11	11	14	10
Total	37	38	41	36	46	41
Average car-load, tons	15.6	17.5	16.3	16.6	22.4	19.7
" train- " "	421.	472.	491.	415.	716.	612.
" haul, miles	213.60	232.58	371.36	244.79	224.59	275.65
Number of passengers	11,882	36,645	4,861	16,426	9,199	9,860
Passenger-miles	1,146,808	1,287,454	526,995	912,375	651,649	682,271
Average journey, miles	96.51	36.79	108.39	55.54	70.84	69.19
" passengers per train	62	61	53	52	52	57
Line-mileage	8,346	6,457	3,614	9,684	7,780	6,325
Mileage per mile of line:						
Freight train	1,697	1,522	2,141	2,044	1,244	1,453
Passenger "	2,218	3,247	2,808	1,814	1,603	1,900
Total	3,915	4,769	4,949	3,858	2,847	3,353
Switching train	755	724	650	1,086	527	804
Average number trains per day:						
Freight	4.6	4.2	5.9	5.6	3.4	4.0
Passenger	6.1	9.0	7.7	5.0	4.4	5.2
Total	10.7	13.2	13.6	10.6	7.8	9.2
Ratio to line-mileage:						
Average haul	0.032	0.036	0.103	0.025	0.029	0.043
Average journey	0.011	0.005	0.030	0.005	0.009	0.010

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	Denver & Rio Grande	Colorado & Southern	Midland Valley	San Pedro, Los Angeles & Salt Lake	Arizona Eastern	Butte, Anaconda & Pacific
Tons freight	11,230	4,822	1,125	3,401	3,905	6,074
Ton-miles	1,420,196	542,077	85,930	602,653	134,170	164,424
Freight train-miles	3,674	1,582	357	1,737	256	255
Passenger " "	3,259	1,229	453	2,308	319	90
Switching " "	1,807	771	118	437	126	274
Total	8,740	3,582	928	4,482	701	619
Freight per cent.	42	44	38	40	37	41
Passenger " "	38	34	49	50	45	15
Switching " "	20	22	13	10	18	44
Car-miles, loaded	69,973	24,368	4,085	31,709	4,196	3,457
" " empty	31,941	13,689	3,056	15,154	2,347	3,136
Total	101,914	38,057	7,141	46,863	6,543	6,593
Per cent., loaded	69	64	57	67	64	52
" " empty	31	36	43	32	36	48
Loaded cars per train	19	15	11	18	14	14
Empty " " "	9	8	8	9	8	12
Total	28	23	19	27	22	26
Average car-load, tons	20.4	21.6	21.03	18.7	32.1	46.
" train- " "	387.	324.	221.	336.	450.	643.
" haul, miles	126.46	112.40	76.35	177.17	34.35	27.07
Number of passengers	1,820	1,084	655	1,498	321	324
Passenger-miles	248,876	55,809	19,360	122,381	10,787	5,978
Average journey, miles	136.69	51.45	29.76	81.67	33.57	18.43
" passengers per train	76	45	42	53	34	66
Line-mileage	2,583	1,127	380	1,133	367	91
Mileage per mile of line:						
Freight train	1,424	1,404	939	1,533	697	2,802
Passenger "	1,263	1,090	1,192	2,037	869	990
Total	2,687	2,494	2,131	3,570	1,566	3,792
Switching train	700	684	310	385	343	2,701
Average number trains per day:						
Freight	3.9	3.8	2.6	4.2	2.0	7.7
Passenger	3.5	3.0	3.3	5.7	2.4	2.7
Total	7.4	6.8	5.9	9.9	4.4	10.4
Ratio to line-mileage:						
Average haul	0.049	0.100	0.201	0.156	0.093	0.300
Average journey	0.053	0.045	0.078	0.072	0.091	0.202

XIX. Special Statistics — *Continued*

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT — *Continued*

Railroad	Oregon Short Line	Oregon-Washington	Western Pacific	North Western Pacific	Spokane, Portland & Seattle	Spokane International
Tons freight	5,931	5,867	1,200	1,142	1,137	720
Ton-miles	1,623,207	1,033,051	595,826	38,976	300,550	58,486
Freight train-miles	2,973	1,982	1,460	318	424	171
Passenger " "	3,595	3,221	1,318	1,339	1,018	196
Switching " "	1,419	910	263	141	220	54
Total	7,987	6,113	3,041	1,798	1,662	421
Freight per cent.	37	32	48	18	26	41
Passenger " "	45	53	43	74	61	46
Switching " "	18	15	9	8	13	13
Car-miles, loaded	74,378	47,163	32,627	3,042	14,844	2,537
" " empty	28,827	14,627	14,370	1,273	2,063	1,090
Total	103,205	61,790	46,997	4,315	16,907	3,627
Per cent., loaded	72	76	69	74	88	70
" " empty	28	24	31	26	12	30
Loaded cars per train	23	21	23	10	33	13
Empty " " "	9	6	10	4	5	6
Total	32	27	33	14	38	19
Average car-load, tons	21.82	21.9	18.26	12.2	20.25	22.05
" train- " "	498.	447.	408.	122.	662.	302.
" haul, miles	273.68	176.08	496.55	34.13	264.3	81.14
Number of passengers	2,258	2,460	236	7,431	1,039	117
Passenger-miles	190,167	185,389	62,075	126,073	68,015	8,053
Average journey, miles	84.20	75.36	26,285	16.96	65.42	68.33
" passengers per train	53	58	48	95	67	41
Line-mileage	2,069	1,915	939	400	557	163
Mileage per mile of line:						
Freight train	1,437	1,004	1,555	795	761	1,050
Passenger "	1,740	1,695	1,404	3,347	1,827	1,203
Total	3,177	2,699	2,959	4,142	2,588	2,253
Switching train	686	479	280	352	393	332
Average number trains per day:						
Freight	3.9	3.0	4.3	3.7	2.1	2.9
Passenger	4.7	4.6	3.9	9.2	5.0	3.3
Total	8.6	7.6	8.2	12.9	7.1	6.2
Ratio to line-mileage:						
Average haul	0.132	0.092	0.529	0.085	0.474	0.500
Average journey	0.040	0.039	0.280	0.424	0.117	0.419

XIX. Special Statistics — *Continued.* Comparative Performance

Train-miles and Car-miles given in Thousands

WESTERN DISTRICT

	General Average	Special Maxima and Minima			
Number of roads	70	42	60 per cent.		
Line-mileage	126,277	115,689	91 per cent.		
		Maxima		Minima	
		Road		Road	
Tons of freight	481,263	Chicago & N. Western	43,309	Midland Valley	1,125
Ton-miles	92,284,883	Chi., Burl'n & Quincy	8,612,629	" "	85,930
Freight train-miles	216,715	Chi., Mil. & St. Paul	19,700	Butte, Anac'a & Pac.	255
Passenger " "	242,313	Southern Pacific	20,968	" " "	90
Switching " "	101,185	Chi., Mil. & St. Paul	10,514	Midland Valley	118
Total	560,213	" " "	47,781	Butte, Anac'a & Pac.	619
Freight train-miles per cent.	39	Duluth & Iron Range	60	North Western Pac.	18
Passenger train-miles per cent.	43	Union Pacific	50	Duluth & Iron Range.	14
Switching train-miles	18	Butte, Anac'a & Pac.	44	North Western Pac.	8
Car-miles, loaded	5,042,977	Chi., Mil. & St. Paul	489,450	Spokane Internat'l	2,537
" " empty	2,165,799	Chi., Burl'n & Quincy	212,332	" "	1,090
Total	7,208,776	Chi., Mil. & St. Paul	687,690	" "	3,627
Per cent., loaded	70	Spokane, Portland & Seattle	88	Butte, Anac'a & Pac.	52
" " empty	30	Butte, Anac'a & Pac.	48	Spokane, Portland & Seattle	12
Loaded cars per train	23.2	Spokane, Portland & Seattle	33	North Western Pac.	10
Empty " " "	10.0	Duluth, Missabe & Northern	20	" " "	4
Total	33.2	Great Northern	46	" " "	14
Average car-load, tons	18.4	Butte, Anac'a & Pac.	46.	" " "	12.2
" train- " "	427.	Duluth, Missabe & Northern	1,108.	" " "	12.2
" haul, miles	191.76	Western Pacific	496.55	Butte, Anac'a & Pac.	27.07
Number of passengers	271,829	Southern Pacific	36,645	Spokane Internat'l.	117
Passenger-miles	13,633,090	Chi. & North Western	1,173,435	Butte, Anac'a & Pac.	5,978
Average journey	50.15	Denver & Rio Grande	136.69	North Western Pac.	16.96
" passengers per train	56	North Western Pac.	95	El Paso & So. West'n	31
Line-mileage	126,277	Chi., Mil. & St. Paul	9,684	Butte, Anac'a & Pac.	91
Mileage per mile of line:					
Freight train	1,720	Duluth & Iron Range	3,546	Arizona Eastern	697
Passenger "	1,923	Chicago & Alton	3,353	" "	869
Total	3,643	" "	6,536	" "	1,566
Switching train	803	Duluth & Iron Range	4,461	Western Pacific	280
Average number trains per day:					
Freight	4.7	" " "	9.7	Arizona Eastern	2.
Passenger	5.3	Chicago & Alton	9.2	" "	2.4
Total	10.0	" "	17.6	" "	4.4
Ratio to line-mileage:					
Average haul		Western Pacific	0.529	Chi. & North Western	0.017
Average journey		Spokane Internat'l	0.419	" " "	0.004

XIX. Special Statistics — *Continued.* Comparative Performance

Train-miles and Car-miles given in Thousands

UNITED STATES

	General Average	Special Maxima and Minima			
Number of roads	180	96	63 per cent.		
Line-mileage	227,000	201,000	89 per cent.		
		Maxima		Minima	
		Road		Road	
Tons of freight	1,843,216	Pennsylvania	135,054	Atlanta & West Point	776
Ton-miles	280,924,749	"	22,174,791	Atlantic City	34,070
Freight train-miles	590,834	"	30,272	Atlanta & West Point	192
Passenger " "	580,792	"	29,303	Butte, Anac'a & Pacific	90
Switching " "	329,219	"	25,366	Atlanta & West Point	15
Total	1,500,845	"	84,941	" " "	583
Freight train-miles per cent.	39	N. Y., Chi. & St. Louis	63	Long Island	8
Passenger train-miles per cent.	39	Long Island	82	N. Y., Chi. & St. Louis	13.8
Switching train-miles per cent.	22	Wheeling & Lake Erie	67	Atlanta & West Point	3
Car-miles, loaded	13,507,267	Pennsylvania	789,095	Spokane Internat'l	2,537
" " empty	6,426,178	"	431,272	Atlantic City	940
Total	19,933,445	"	1,210,367	" "	3,547
Per cent., loaded	68	Spokane, Portland & Seattle	88	Butte, Anac'a & Pac.	52
" " empty	32	Butte, Anac'a & Pac.	48	Spokane, Portland & Seattle	12
Loaded cars per train	22.9	Lake Shore & Mich. So.	34	Northwest'n Pac.	10
Empty " " "	10.9	Virginian	26	" "	4
Total	33.8	"	57	" "	14
Average car-load, tons	21.1	Butte, Anac'a & Pac.	46	" "	10
" train- " "	483.	Virginian	1409	" "	122
" haul, miles	154.58	Western Pacific	496	Long Island	22
Number of passengers	1,002,350	N. Y., N. H. & Hartford	87,183	Spokane Internat'l	117
Passenger-miles	34,566,985	N. Y. C. & Hudson Riv.	1,983,885	Butte, Anac'a & Pac.	5,976
Average journey	34.49	Denver & Rio Grande	136.68	Phila. & Reading	15.16
" passengers per train	59	Long Island	110	Virginian	27
Line-mileage	227,000	Chi., Mil. & St. Paul	9,684	Rich'd, Fred'bg & Pot.	88
Mileage per mile of line:					
Freight train	2,603	N. Y., Chi. & St. Louis	9,679	Arizona Eastern	697
Passenger "	2,558	Rich'd, Fred'bg & Pot.	8,756	Virginian	853
Total	5,161	" " "	15,031	Arizona Eastern	1,560
Switching train	1,450	Pittsburgh & L. Erie	14,068	Atlanta & West Point	161
Average number trains per day:					
Freight	7.1	N. Y., Chi. & St. Louis	26.5	Arizona Eastern	2
Passenger	7.0	Long Island	37.7	" "	2.4
Total	14.1	" "	41.4	" "	4.4
Ratio to line-mileage:					
Average haul		Rich'd, Fred'bg & Po.	0.787	Chi. & North Western	0.017
Average journey		" " "	0.527	" " "	0.004

XX. DENSITY OF PASSENGER TRAFFIC IN 1914 ON SOME OF THE LONGER RAILROAD LINES IN THE UNITED STATES

RAILROADS	LINE MILEAGE	PASSENGER-MILES PER MILE OF LINE	AVERAGE NUMBER OF PASSENGERS PER TRAIN	AVERAGE JOURNEY PER PASSENGER MILES
Eastern District — Trunk Lines				
Baltimore & Ohio	4,478	185,000	49	36.39
Pennsylvania	4,084	481,000	67	25.16
N.Y. Central & Hudson River	3,756	573,000	71	36.94
Erie	1,988	307,000	67	22.66
Southern District — Trunk Lines				
Southern	7,033	126,000	46	45.24
Atlantic Coast Line	4,646	89,000	49	45.60
Seaboard Air Line	3,084	80,000	41	48.13
Louisville & Nashville	4,937	116,000	54	43.22
Illinois Central	4,767	150,000	54	26.12
Western District — Transcontinental Lines				
Chicago, Milwaukee & St. Paul	9,684	94,000	52	55.54
Atchison, Topeka & Santa Fé	8,346	137,000	62	96.51
Great Northern	7,780	83,000	52	70.84
Southern Pacific	6,457	199,000	61	36.79
Northern Pacific	6,325	107,000	57	69.19
Union Pacific	3,614	146,000	53	108.39

XXI. DENSITY OF FREIGHT TRAFFIC IN 1914 ON SOME OF THE LONGER RAILROAD LINES IN THE UNITED STATES

RAILROADS	LINE MILEAGE	TON-MILES PER MILE OF LINE	AVERAGE TONS PER TRAIN	AVERAGE TONS PER CAR-LOAD	AVERAGE HAUL, MILES
Eastern District — Trunk Lines					
Baltimore & Ohio	4,478	2,997,000	632	25.3	193.50
Pennsylvania	4,084	5,430,000	732	28.2	164.19
N. Y. Central & Hudson River	3,756	2,778,000	512	18.3	203.54
Erie	1,988	3,223,000	598	21.4	171.89
Southern District — Trunk Lines					
Southern	7,033	651,000	299	15.7	154.61
Atlantic Coast Line	4,646	439,000	240	12.9	155.59
Seaboard Air Line	3,084	510,000	278	14.6	151.28
Louisville & Nashville	4,937	1,116,000	309	20.6	171.09
Illinois Central	4,767	1,633,000	423	20.1	240.83
Western District — Transcontinental Lines					
Chicago, Milwaukee & St. Paul	9,684	834,000	415	16.6	244.79
Atchison, Topeka & Santa Fé	8,346	706,000	421	15.6	273.60
Great Northern	7,780	891,000	716	22.4	224.59
Southern Pacific	6,457	732,000	472	17.5	232.58
Northern Pacific	6,325	890,000	612	19.7	275.65
Union Pacific	3,614	1,051,000	491	16.3	371.36

XXII. Density of Passenger Traffic in 1914, per Mile of Line

Passenger-miles given in Thousands

United States . . . 152 (=152,000)

Eastern District	278
Long Island	1,512
West Jersey & Sea Shore .	836
N. Y., N. H. & Hartford .	802
Atlantic City	744
Phila., Balto. & Wash'n .	607
Del.,Lackawanna & West'n	580
N. Y. C. & Hudson River .	573
Central of New Jersey . .	557
Pennsylvania	481
Pittsburgh & Lake Erie .	431
Lake Shore & Mich. So'n .	423
Boston & Maine	397
Philadelphia & Reading .	363
Pittsb'gh, Cin., Chi. & St. L.	309
Erie	307
Pennsylvania Co. . . .	293
Northern Central . . .	265
Michigan Central . . .	250
Clevel'd, Cin., Chi. & St. L.	207
Baltimore & Ohio . . .	185
Lehigh Valley	184
N. Y., Chicago & St. Louis.	180
Delaware & Hudson . .	172
Grand Rapids & Indiana .	164
Wabash	151
Chi., Ind'p'lis & Louisville	149
Hocking Valley	139
Chicago & East'n Illinois .	129
Vandalia	128
Bessemer & Lake Erie . .	114
Buffalo, Roch. & Pittsb'gh	96
Cin., Hamilton & Dayton .	95
Pere Marquette	89
Wheeling & Lake Erie . .	87
Western Maryland . . .	82

Southern District	109
Rich'd, Fred'g & Potomac	508
Cin., N. O. & Texas Pac. .	287
Atlanta & West Point . .	279
Illinois Central	150
Southern	126
Chesapeake & Ohio . .	124
Louisville & Nashville . .	116
Norfolk & Western . .	113
Nashv., Chatt'a & St. L. .	112
Florida East Coast . . .	110
Central of Georgia . . .	94
Atlantic Coast Line . .	89
Yazoo & Miss. Valley . .	83
Seaboard Air Line . . .	80
Mobile & Ohio	61
Atlanta, Birming'm & Atl.	47
Car., Clinchfield & Ohio .	39
Virginian	30

Western District	108
North Western Pacific . .	314
Chicago & Alton . . .	211
Southern Pacific	199
Chi., St. P., Min. & Omaha	152
Union Pacific	146
Chicago & Northwestern .	145
Atch., Topeka & Santa Fé	137
Chi., Burlington & Quincy	126
Chi., Rock Island & Pac. .	123
Spokane, Portl'd & Seattle	122
Galv., Harrisb'g & San Antonio	115

Western District	108
S. Pedro, Los Ang. & Salt Lake	108
Northern Pacific	107
Chicago Great Western .	107
St. Louis-San Francisco .	106
Missouri, Kansas & Texas .	103
Texas & Pacific	101
Oregon-Washington . . .	97
Denver & Rio Grande . .	96
Houston & Texas Central .	95
Chi., Milwaukee & St. Paul	94
Oregon Short Line . . .	91
Kansas City Southern . .	88
St. L., Iron Mtn. & South'n	85
Great Northern	83
Gulf, Col'o & Santa Fé . .	82
Minn., St. P. & S. Ste. Marie	81
Duluth, Winnipeg & Pac. .	78
Internat'l & Gt. Northern .	77
St. Louis Southwestern .	72
Duluth, So. Shore & Atlantic	71
Missouri Pacific	66
Western Pacific	66
Butte, Anac'a & Pac. . .	65
Minneapolis & St. Louis .	58
Duluth, Missabe & North'n	54
Colorado & Southern . .	52
Duluth & Iron Range . .	52
Midland Valley	50
Spokane Internat'l . . .	49
Arizona Eastern	29

XXIII. Density of Freight Traffic in 1914, per Mile of Line

Ton-miles given in Thousands

United States . . . . 1,255 (=1,255,000)

Eastern District	2,439
Pittsburgh & Lake Erie .	9,043
Bessemer & Lake Erie . .	8,564
Pennsylvania	5,430
Philadelphia & Reading .	4,916
Pennsylvania Co. . . .	4,448
Del.,Lackawanna & West'n	4,255
Hocking Valley	3,742
Lehigh Valley	3,624
Central of New Jersey . .	3,500
Northern Central . . .	3,456

Eastern District	2,439
Buffalo, Roch. & Pittsb'gh	3,405
N. Y., Chicago & St. Louis	3,322
Delaware & Hudson . .	3,259
Lake Shore & Mich. South'n	3,250
Erie	3,223
Pittsb'gh, Cin., Chi. & St. L.	3,150
Baltimore & Ohio . . .	2,997
N. Y. C. & Hudson Riv. .	2,788
Wheeling & Lake Erie .	2,597
Elgin, Joliet & Eastern .	2,006

Eastern District	2,439
Clevel'd, Cin., Chi. & St. L.	1,896
Western Maryland . . .	1,877
Michigan Central . . .	1,785
Chicago & East'n Illinois .	1,724
Phila., Balt. & Washington	1,702
Cin., Hamilton & Dayton .	1,454
Wabash	1,320
Vandalia	1,275
Boston & Maine . . .	1,170
N. Y., N. H. & Hartford .	1,151

XXIII. Density of Freight Traffic in 1914, per Mile of Line — *Cont.*

United States . . . . 1,255 (= 1,255,000)

Eastern District	2,439	Southern District	1,177	Western District	798
Chi., Ind'p'lis & Louisville	1,022	Atlanta & West Point . .	501	Chicago & North Western .	771
Grand Rapids & Indiana .	810	Central of Georgia . . .	440	Chi.,St.P., Minn. & Omaha	740
Pere Marquette	778	Atlantic Coast Line . . .	439	Southern Pacific	732
West Jersey & Sea Shore .	277	Florida East Coast . . .	218	Atchison, Topeka & St. F. .	706
Long Island	238			Texas & Pacific	696
Atlantic City	200			Minn., St. P. & S. Ste. Marie	684
				St. Louis Southwestern .	674
		Western District	**798**	Chi., Rock Island & Pacific	639
				Western Pacific	634
Southern District	**1,177**			Gulf, Colorado & Santa Fé	618
		Duluth & Iron Range . .	2,778	St. Louis-San Francisco .	613
		Duluth, Missabe & North'n	2,547	Missouri Pacific	609
Norfolk & Western . . .	4,497	Butte, Anac'a & Pacific .	1,815	Denver & Rio Grande . .	549
Virginian	3,368	Chicago & Alton	1,417	Oregon-Washington . . .	546
Cin., N. O. & Texas Pac. .	3,286	Kansas City Southern . .	1,284	Spokane, Portland & Seattle	539
Chesapeake & Ohio . .	3,011	Union Pacific	1,051	S. Pedro, Los Ang. & Salt L.	531
Rich'd, Fred'g & Potomac	1,938	Duluth, Winnipeg & Pac. .	950	Minneapolis & St. Louis .	516
Illinois Central	1,633	Chicago, Burlington & Q. .	942	Internat'l & Gt. Northern	501
Car., Clinchfield & Ohio .	1,623	St. Louis, Iron Mt. & So. .	926	Missouri, Kansas & Texas .	483
Mobile & Ohio	1,424	Chicago Great Western .	911	Colorado & Southern . .	481
Louisville & Nashville . .	1,116	Great Northern	891	Houston & Texas Central	465
Yazoo & Miss. Valley . .	853	Northern Pacific	890	Duluth, So.Shore & Atlantic	415
Nashv.,Chatt'a & St. Louis	677	Chi., Milwaukee & St. Paul	834	Arizona Eastern	365
Southern	651	El Paso & Southwestern .	788	Spokane International . .	357
Atlanta, Birming'm & Atl'c	565	Oregon Short Line . . .	784	Midland Valley	226
Seaboard Air Line . . .	510	Galv., Harrisb'g & SanAnt'o	783	North Western Pacific . .	97

XXIV. Comparison of Daily Train Sheets

on the same division of the southern railway

November 1, 1895	single track	174 miles
November 1, 1913	double track	85 miles
	single track	87 miles

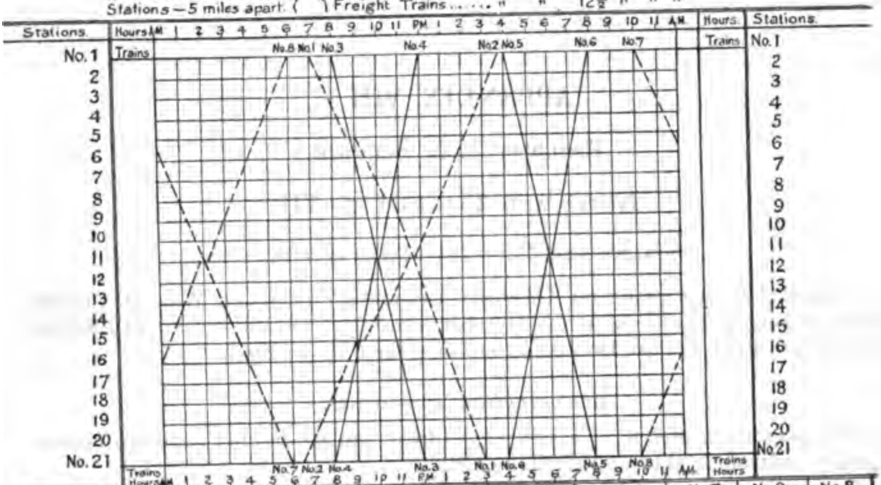
Year	Trains		Mileage		Total	
	Passenger	Freight	Passenger	Freight	Trains	Mileage
1895 single track . .	21	26	2,412	2,067	47	4,479
1913 double track . .	40	30	2,732	2,254	70	4,986
1913 single track . .	27	34	1,871	1,373	61	3,244
For the Division . . .	46	46	4,603	3,627	92	8,230

Train Mileage per Mile of Track

Year	Passenger Trains Miles	Freight Trains Miles	Total Miles
1895 single track	14.53	12.45	26.98
1913 double track	32.18	26.55	58.73
1913 single track	23.04	15.68	38.72
For the Division	27.71	21.24	48.95

XXV. Train-Sheet Diagram.

Line — 100 miles long. Stations — 5 miles apart.
Passenger Trains... Av. Speed, 25 miles an hour. Freight Trains ...... " " $12\frac{1}{2}$ " " "



Passenger Trains	No. 3	No. 5	No. 4	No. 6	Freight Trains	No. 1	No. 7	No. 2	No. 8
Station No. 1 Lv.	A.M. 8.00	P.M. 4.00	M. Ar. 12.00	P.M. 8.00	Station No. 1 Lv.	A.M. 7.00	P.M. 10.00	P.M. Ar. 3.45	A.M. 6.00
" No. 21 Ar.	12.00 M.	8.00 P.M.	Lv. 8.00 A.M.	4.00	" No. 21 Ar.	3.00 P.M.	6.00 A.M.	Lv. 6.30 A.M.	10.00 P.M.

APPENDIX VIII

Railway War Service

Notes and Tables I to VII

I. Scheme for Military Railway Operation

Compiled from a paper on "Military Railways," by Major Wm. D. Connor, Corps of Engineers, U. S. Army, Member Am. Soc. C. E. Prepared in 1905 and published in 1910, as Pub. Doc. 359. Office of the Chief of Engineers.

ORGANIZATION AND DUTIES

The persons in charge of a military railway can be divided into two classes: military controlling staff and civilian officials.

The military controlling staff will be chosen from engineer officers and others who have had railway experience, and their function is to make known the military desires and to see that the roads are operated so as to attain these ends. Having given their instructions, they allow the civilian officials and employees to work out the technical details in the manner dictated by their railway experience. The military staff will only interfere in cases where they believe that the civil officials are not endeavoring to carry out the military plans, or are not succeeding in doing so.

MILITARY RAILWAY STAFF

Director of Railways (D.R.)

All railways under military control must be under the direction of one head, known as the Director of Railways (D.R.) If there is only one theater of operations, this officer will be on the staff of the General Commanding (G.C.) in the field. If there are several theaters, his headquarters will be where he can best supervise the work of all the railways; and the railways in any particular theater will be under an assistant, known as the Director of Railways of that particular army.

The duties of the D.R. of an army and his staff are: to operate the railroads so as to promote the plans of the G.C., to supply the military knowledge not possessed by the technical railway staff, and to shield the railway operatives and officials from unauthorized *military interference.*

The D.R. receives his orders from the Chief of Staff (C. of S.) and takes the necessary steps to have them executed by his subordinates. He must know the capacity and condition of each line, and must make arrangements for the prompt and accurate filling of requisitions. He keeps direct control over the armored-train defense of the railways.

Deputy Director of Railways (D.D.R.)

In a large field of operations there will ordinarily be several independent systems of railways. If several such systems are in one *Line of Communications,* they will all be controlled by a Deputy Director of Railways (D.D.R.), who sees to the coöperation of the several lines. He is on the Staff of the *General Commanding the Line of Communications*, and the other military railway officers are subordinate to him.

The D.D.R. will keep fully informed of the condition and capacity of the various systems under his control, and will so distribute the traffic that each road will be kept busy with its share of the work. He will keep track of the rolling stock and will distribute it from one road to another as may be necessary. He will direct railway supplies to points most needful.

Assistant Director of Railways (*A.D.R.*)

To each system will be assigned an Assistant Director of Railways, who may be called the military manager of the road to which he is assigned, the civil manager being the person through whom he controls his civil employees. He is charged with the efficient operation of the line to which he is assigned, including its operation, maintenance, and supply; and he advises the D.R. as to its requirements for defense. He has charge of the special railway police on his line.

Deputy Assistant Director of Railways (*D.A.D.R.*)

To the D.A.D.R. is assigned one or more divisions of the line, depending upon the road, and he may be termed the military superintendent of such divisions. He must keep track, through the car-distributor, of all rolling-stock, and if cars are not promptly unloaded and released, will call the detaining station to account. He is responsible for the maintenance and the regular military police of his division, and for the transportation of troops and supplies within its limits, also for proper sidings, platforms, ramps, stock-yards and watering facilities at the stations.

Railway Transport Officer (*R.T.O.*)

At each of the bases from which military railways are operated, there will be detailed, from the Quartermaster's Department, a Railway Transport Officer, who will be on the staff of the D.D.R. His duties will be, first, to make arrangements with the railway officials for all transportation of troops, animals, supplies, etc.; second, to attend to the loading and unloading of troops and animals at the base; third, to issue transportation from the base for all officers and soldiers not traveling on troop-trains; fourth, to issue permits for and regulate all non-military transportation; fifth, to pay all railway accounts on receipt of the proper vouchers; sixth, to pay all civilian labor employed on the military railways.

He will be notified of the expected arrival of troops, animals or supplies, and will promptly confer with the D.D.R. as to the best route to be followed by them.

Railway Staff Officer (*R.S.O.*)

At each important station there will be detailed a Railway Staff Officer, who will be independent of the Commanding Officer of any troops that may be stationed at that point, and will be on the staff of the A.D.R.

He will be in charge of all railway employees while at that station, and will execute such authority, as a general rule, through the local station-agent. He will look after the loading and unloading of troops and supplies, and will be responsible that all cars are promptly unloaded and released, and that no empty cars are asked to be sent to the station before the cargo will be ready for loading. He will make arrangements for food and hot coffee for troops en route through the station, upon notification from the proper authority.

He will issue, on proper authority, all transportation from the station, and forward with his indorsement all communications from the local officers to the railway officials.

He will keep the D.A.D.R. informed as to all station requirements, and will report daily to him the organizations or parts of organizations that depart from or arrive at his station, and include the following data: destination, or starting point; the number of officers, men, guns, horses, vehicles, and the amount of supplies in each train; the number of the train and the time of its departure or arrival. The D.A.D.R. will consolidate these reports for each week, and render the consolidated report to the A.D.R., with such other information as to the movements as may be desired.

The R.S.O. is authorized to call on the Commanding Officer of the station for the necessary details to unload the cars immediately upon their arrival. If for any reason he can not get such details, or can not unload the cars inside of 48 hours, he will report the facts to the D.A.D.R. by telegraph.

He is responsible that no railway buildings or property are used by the troops at the station, when necessary for railroad use, and before permission is given for such military use, authority will be obtained from the D.A.D.R.

Upon the arrival of troop trains, the R.S.O. will be present and give the Commanding Officer on the train all information and proper assistance.

At stations where there is no R.S.O., the Commanding Officer of the station will carry out the military duties, and the station-agent perform the railway duties of the R.S.O.

LINE OF COMMUNICATIONS

Operation

As soon as a railroad is taken under military control, a bulletin should be published, giving the capacity of cars, and the maximum number of cars, loaded and empty, to be run in trains, where the whole tonnage-rating of the engines can not be utilized. The carrying capacity of coaches and other cars should be given for both *normal transportation* and for *hurried transportation;* the former will be used unless the other be specifically stated, in which case trains will be made to carry every available man that safety will permit.

The assignment of troops to trains will rest with the railway officials. Where regiments carry tentage and camp equipage, these will normally be sent ahead of the troops in one train and will not be divided up amongst the trains carrying the troops. The baggage of the companies traveling on different trains will be kept separate, so that the baggage of each can be shipped in the train with the company. In infantry regiments, the officers' horses will be shipped ahead in the train with the camp-equipage. In mounted regiments, the first trains will carry the horses, and men to look after them, with the picket lines and a proper amount of forage. Guns, caissons and wagons will follow on trains in the rear of the regiments to which they belong. Wagons will be loaded from a platform or from portable ramps. They will be loaded on one car and run along over the train to the car on which they are to be carried. The openings between the cars are to be covered by plates of iron. The loading of a heavy vehicle will be facilitated by hooking a rope to it and drawing it along by a team on the ground, while it is guided by the tongue.

Police. A force of railway police should be organized to detect thefts or issuance of bogus transportation, to prevent interference with railway operation or destruction of property. It should assist in the detection of spies, of employees who illegally transport liquor, and of mail that may have been forbidden by the censor. Certain of the detective force should be directly under the A.D.R. and the others under the division superintendent.

MAINTENANCE OF WAY

This department should be so organized as to be able promptly to repair any break of any nature. A large maintenance force should be kept on each division at all times fully prepared for emergencies, even when ordinarily utilized for other purposes.

Maintenance work is divided into water supply, track-work and bridge-work, each in charge of a supervisor.

Water supply. The apparatus should have, as far as practicable, interchangeable parts, of which an extra supply should be always conveniently at hand. The supervisor should have a car stored with the parts likely to be destroyed by an enemy, and should be supplied with a gasoline motor-car.

Track repairs. A special gang of trackmen should be kept together, equipped with tools and supplies, ready to start on short notice. This gang should move in a train of bunk-cars, cars for tools and supplies, and a kitchen-car. Several portable forges should be part of its outfit. There should be a mechanic to every 6 laborers and a cook to every 30 men.

Bridge repairs. The supervisor should thoroughly acquaint himself with the location and character of every opening in the track on his division. He should be provided with drawings and bills of material for every bridge, and a stock of materials classified in standard dimensions.

The organization is similar to that of the track-repair gang; except that a greater number of mechanics is required, severally skilled in steel, masonry and wood-work. The repair-train is also similarly organized, with additions of timber, blocking, girders, derrick and other appliances for rapid work. One car should be made up as a concrete car and carry concrete materials.

Labor bureau. All labor on military railways should be employed through an army labor bureau, which should fix the wages, schedules and other terms and conditions of employment. Requisitions for laborers should state the number and kind desired.

FIELD OF ACTION

Field division. In the immediate vicinity of active operations, it is essential that the railway service should be specially organized under an A.D.R. Usually the division extends for 40 to 50 miles in the rear of the rail-head to a station designated as the transfer-station or advanced base. The Field A.D.R. is assisted by a D.A.D.R. in charge of the operating department and a Construction Engineer in charge of the track-work.

Advanced base. The advanced base should be maintained within 40 or 50 miles of the rail-head, stocked with an ample supply of tools and stores. If stores arriving at the rail-head can not be promptly unloaded, the loaded cars should be at once returned to the advanced base, to prevent blocking the line. Precedence should be given to trains and supplies for construction-work, except possibly during an engagement. Army-stores unloaded at the rail-head should not be reloaded for further shipment toward the front, except under great emergency, until traffic at that point has become normal. Less delay will be caused by getting up new shipments.

Platforms and portable ramps should be provided near the rail-head for unloading troops and animals. When in use, the ramps should be lashed to the truss-rods under the cars.

Construction-work. The Construction Engineer is charged with temporary repairs only. The more permanent repairs are made later by the maintenance department of the Communications Division.

The construction-train on the Field Division should consist of a tank-car, a coal-car, dynamo-car, combination office-car, three tourist-cars for laborers and three for engineer troops, one box-car for fine tools and stores, one flat-car loaded with timber, 12 x 12, 16 x 8 and 18 x 9 inches, two flat-cars with ties and two with rails. The office-car should be connected with the rear telegraph and telephone. The train should carry an electric-light plant and ten days' rations. A derrick-car should be kept near the rail-head for use in reconstructing bridges and for removing débris from wrecked structures.

Construction wagon-trains. A train of 30 or 40 wagons should be organized, with a working party and supplies, for such repairs as can be made in advance of track-laying.

Camp-equipage should be provided sufficient to house the men comfortably in inclement weather.

Night-work. For field-use, "Wells lights" are useful. For bridge-work, electric lights are preferable to acetylene lamps, which throw a very black shadow.

Cable-ways facilitate the reconstruction of bridges. A light cable-way has a capacity of 60 tons per hour for spans up to 400 feet, and for 25 tons for spans up to 1000 feet. A balanced cable-crane is useful for transporting supplies while a bridge is under construction.

DEMOLITION

Bridges. The lower chords and batter posts of trusses and the abutments and piers of girder-bridges are readily demolished by high explosives, ignited by an electric exploder. Arches are destroyed by exploding a charge in a shaft sunk from above, and abutments by exploding a charge in a shaft behind the masonry.

Tunnels may be blocked by blowing in the top from shafts. Two trains loaded with rails and started into a tunnel from the ends at the same time will effectually block it by the ensuing collision.

Track may be speedily demolished by blowing up alternate joints, or by fires built every hundred feet on top of the rails.

ARMORED TRAINS

Organization. All armored trains are under the control of the D.R., and in immediate charge of an A.D.R. of Armored Trains, who orders them from point to point under the direction of the C. of S. of the Army, and is himself responsible for the equipment, garrison and working of such trains.

The C.O. of the train, on being ordered to a certain section, reports to the C.O. of the Railway Guard of that section for orders. He should, however, keep in communication with the A.D.R., and, when ordered to another section, must first notify the C.O. of the section which he is leaving. He must also inform the train-dispatcher of his intended movements, using the signal which gives immediate right-of-way over the wires. He must not use this privilege to interfere with the regular traffic except in emergencies.

Make-up. The train should be made up from front to rear, as follows:

(1) Gondola car, (2) No. 1 Machine-gun car, (3) Dynamo-car, (4) Office-car, (5) Baggage-car, (6) Locomotive, (7) R.F.-gun car, (8) Other cars as required, (9) Dynamo-car, (10) No. 2 Machine-gun car.

The cars should open end-to-end with intervening platforms, and with telephone and bell connections through the train, with slip-couplings between the cars. A signal should be arranged to order the release of the air-brakes in case the hose is cut, when resort must be had to inside hand-brakes.

The gondola car, loaded with sand and with a cow-catcher on the front end, is intended for protection from contact-mines.

A combination diner and sleeper is used for the office-car, with a telegraph office and a kitchen sufficient to provide for the train-crew and garrison.

Tourist-sleepers are required for the enlisted men and also a baggage-car; and flat-cars loaded with ties, rails and spikes.

Armor. The vital parts of the locomotive should be protected by bullet-proof armor, and the rear of the cab from reverse fire. The sides of the cab should be provided with sliding steel-plate windows and with small hoods with slits, fore and aft, through which the track and signals may be observed without personal exposure.

The sides of the machine-gun and dynamo cars should be plated with ½-inch steel for a height of seven feet and be slotted for rifle-fire. The side-doors of the machine-gun cars should be arranged with protected sections that can be swung out on a hinge, to give a flank fire in both directions, and the sides and ends provided with protected port-holes for machine-guns.

Cars can be armored by putting up rails along the sides and ends, securely fastened against disturbance by the motion or jarring of the train. One rail should be omitted at the proper height for loophole rifle-fire. The rails and ties carried on the train can be used for this purpose.

The train should be equipped with two 12-inch search-lights, operated by gasoline power for a dynamo of about two kilowatts. The projector should be armored on all sides, with a sliding-door in front, and should be maneuvered from the inside of the car. The search-lights should be placed on the machine-gun cars, and there should be also one on the locomotive for use when available.

Armament. The armament should consist of four machine-guns with 30,000 rounds of ammunition for each, and two 3-inch R.F. guns on pedestal mounts, each with 500 rounds of ammunition, and manned also by an infantry detail of 12 men to each car.

A 6-inch gun can be mounted on a flat-car and fired in a direction of 30 degrees on either side of the track, without danger of upsetting the car. It can be fired at right angles by the use of two timbers shoved under the car and blocked up tight against the floor.

Garrison. The garrison of the train should consist of an infantry and an artillery officer and of enlisted men as follows: Infantry, 8 non-coms. and 42 privates, Artillery, 3 non-coms. and 7 men, Hospital corps, 2 non-coms., Signal corps, 1 operator and 1 lineman. There should also be a double train-crew.

TACTICS IN ACTION

Armored trains may be used as follows:

(1) To intercept and attack a retreating enemy whom the army is driving on to the railroad line.

(2) On the flank of a column or line of columns, the train being well advanced, to prevent the enemy from moving around that flank.

(3) To reinforce stations and camps that are threatened by the enemy.

(4) To escort ordinary trains.

(5) To reconnoiter.

(6) To patrol the railroad.

In the first two uses, each train should keep moving back and forth over its section; while foot-patrols are also on the track, provided with rockets and fusees. By a system of signals, blockhouses should notify the trains of the presence of the enemy. Each train should halt at prearranged intervals of time, not more than two and a half hours apart, for communication with other trains and with neighboring stations. Search-lights should be freely used in the second case, but not at all in the first one.

In escorting ordinary trains over long distances, they are run in fleets; or singly where the threatened section is short. In handling trains in fleets, the rate of speed is necessarily slow, to prevent collisions. The position of the armored train is normally behind the first train; though, to give the engineman of the leading-train confidence, it is sometimes advisable for the armored train to take the lead. The escort-cars of the whole fleet should be in the last train, except one car in advance of the leading-engine.

For reconnoitering toward a large force of the enemy, the train should be used in conjunction with mounted troops to assure the safety of the railway behind the train and to scout on the flanks, the train keeping well in advance of the horsemen. Deep cuts should be reconnoitered by them before the trains enter.

The machine-gun cars and the R.F.-gun car are self-supporting against a small force and are practically impregnable against infantry-fire.

The general practice, when in action, is to extend the line by distributing the armored cars along the track at such a distance that the rear car can not be turned, the cars being within rifle-range of each other and not over 1000 yards apart. If the enemy is at long range, as the train advances it is cut apart just ahead of the R.F.-gun car and the locomotive pushes the forward part of the train within easy rifle-range, cuts off the machine-gun car and the dynamo-car, and retires to the rear part of the train. If an attempt is made against the rear, this part of the train is backed down the line and the R.F.-gun car and the locomotive return to their former position.

In patrolling service, the train need not be always in motion, but may lie in a cut or behind a hill and send out scouts on foot. In patrolling at night, when ordinary traffic is suspended, switches should be kept closed, so that trains may pass through the stations without whistling.

II. Regulations Affecting the Use of Armored Trains in the South African War

1. In conjunction with columns in the field, to intercept the enemy whom the columns are driving on to the line.
2. To act on the flank of a column or line of columns, the train being well advanced so as to prevent the enemy breaking to that flank.
3. To reinforce stations and camps on the railway which are threatened by the enemy.
4. To escort ordinary traffic trains.
5. To reconnoiter.
6. To patrol by day and night.
7. To protect traffic-routes generally.

The garrison of an armored train consists of an infantry-escort and Royal Artillery and Royal Engineer detachments. The R. E. detachment consists of one N.C.O. and six sappers skilled in railway repairing work and in re-setting derailed engines and trucks; two telegraph-linesmen; one telegraph-clerk; two engine-drivers and two firemen. When the train is engaged, all counted as effective rifles, with the exception of the driver and firemen on the footplate, and even they are to carry rifles in the engine-cab for use against an enemy endeavoring to gain possession of the engine.

Responsibility for the efficiency of the garrisons is placed upon the Assistant-Director of Armored Trains. Whenever, also, a concentration of the trains is decided upon, he is to attach himself to one of them, and take charge of the concerted action of the whole.

"The Rise of Rail Power in War and Conquest," E. A. Pratt, p. 251.

III. Organization of Railway Service under General Order No. 108, War Department, U. S. Army. August 15, 1917

General Construction Service.
Regimental Headquarters.
6 Engineer Companies (Construction).
6 Service Battalions . . . . 4 Companies each.

Engineer Supply Service.
Regimental Headquarters.
2 Engineer Battalions (Supply) . . . . 4 Companies each.
2 " " (Work-shops) . . . . 3 " "
3 Service " . . . . 4 " "

Forestry Service — 20th Engineer Regiment — National Army.
Regimental Headquarters.
10 Engineer Battalions (Forestry) . . . . 3 Companies each.
9 Service " . . . . 4 " "

Quarry Service.
Regimental Headquarters.
2 Engineer Battalions (Quarry) . . . . 3 Companies each.
3 Service " . . . . 4 " "

Light Railway Service. Construction Dep't. 21st Engineer Reg't. National Army.
Regimental Headquarters.
5 Engineer Battalions (Railway) . . . . 3 Companies each.
3 Service " . . . . 4 " "

Operation and Mechanical Dept.
Regimental Headquarters.
4 Engineer Battalions (Railway) . . . . 3 Companies each.
3 Service " . . . . 4 " "

Standard Gauge Railway Service.

Construction Dep't. 11th, 12th, 13th, 14th, 15th, 16th, 17th, and 18th Engineer Regiments — National Army.
8 Service Battalions . . . . 4 Companies each.

Operation and Maintenance Depts.
2 Regimental Headquarters.
6 Engineer Battalions (Railway) . . . . 3 Companies each.
3 Service " . . . . 4 " "

Mechanical and Supply Depts. 19th Engineer Reg't, National Army.
1 Engineer Regiment (Shop).
1 " Battalion (Railway) . . . . 3 Companies.
1 Service " . . . . 4 "

	Officers	Men
Regimental Headquarters. Colonel, Lieut. Col., Captains 3	5	38
Engineer Battalion Headquarters. Major, Captains 2, 1st Lieut.	4	24
Engineer Company. Captain, 1st Lieut.'s 3, 2d Lieut.'s 2	6	250
Service Battalion Headquarters. Major, 1st Lieut., 2d Lieut.	3	6
Service Company. Captain, 1st Lieut., 2d Lieut.	3	250

Light Railway Service — enlisted men	13,078
Standard " " " "	27,038
Total	40,116

Wagon and truck companies organized from engineer personnel.
Medical assignment for each unit.
Railway operating and shop troops, forestry troops and service battalions equipped as infantry, but only ten per cent. armed, except during training.
Non-commissioned officers armed with pistols.
All other special engineer troops armed as divisional engineer troops.

Each regiment is commanded by a U. S. Engineer officer with an army officer as adjutant. The Lieutenant Colonel is a railroad chief engineer. The Captains are engineers of maintenance-of-way, the Lieutenants are supervisors or road-masters, and the non-commissioned officers are track-foremen or bridge-foremen. The privates are track-laborers.

The shop-regiment for repairs of locomotives has a Superintendent of Motive Power for Lieutenant Colonel; the Captains are master mechanics, the Lieutenants are shop-foremen and the non-commissioned officers are gang-foremen. The privates consist of 450 machinists, 175 boiler-makers, 175 blacksmiths, 50 pipe-fitters and helpers, 50 cab-builders and tender-repair men, 50 sheet-iron workers, tinsmiths, and coppersmiths, 25 painters, 25 electricians, stationary engineers, and firemen.

The operating regiments have as officers superintendents, train-masters, yard-masters, etc. Each regiment is expected to operate a division of one hundred miles.

The regiments for general construction service, engineer supply service, forestry service, quarry service, and light-railway service are organized under this order. The nine regiments organized in June, 1917, are the 11th to the 19th. The Forestry Regiment is the 20th, and the Light-Railways Construction Regiment is the 21st.

Fourteen regiments have also been organized for the lines of communication.

IV. Canadian Overseas Railway Construction Battalion

In service in France since October, 1916.
Battalion of four companies — 1065 in all.
4 warrant officers, 52 sergeants, 89 corporals, 40 lance-corporals.
Commissioned officers:

Staff — Lieutenant Colonel, two Majors, Captains, an Adjutant, Quartermaster, Paymaster, Surgeon; Transport, Stores and Equipment, and Veterinary officers.

Each company with Major, Captain or second in command, and four Lieutenants.

Transport. — 10 riding horses, 100 mule-teams, 2 motor-cars, 9 heavy motor-trucks, 8 light motor-trucks, field-kitchen, 4 water-carts.

Each company and headquarters is provided with engineers' and surveyors' equipment, also with tools for building roads, bridges, and buildings.

One hundred and thirty cars in three trains are required for moving the battalion in France.

Headquarters on special train, consisting of office-car, car for preparation of plans and reports, tool-car, mess-car, cook-car, and two sleepers. Men in collapsible huts.

Up to June, 1917, seven of these battalions had been sent overseas, with 183 officers and 5130 men, including five divers. They are provided with two 65-ton steam-shovels and three self-propelling, extension-track pile-drivers.

V. Railway Construction at the Front in France by Canadian Troops in April, 1917. Railway Review, August 25, 1917

Miles	Standard Gauge	Narrow Gauge
Located	44.75	57.58
Graded	36.25	64.98
Repaired	43.55	28.74
Track laid	51.50	72.89
Ballasted	46.45	77.84
Surfaced	43.67	49.63
Average maintained	60.70	100.06
Persons		
Average ordinary ranks daily on construction	1,597	2,504
Average on maintenance	686	1,258
Average British unskilled labor	2,660	3,276
Casualties from shell fire		
Officers	—	3
Men	7	75

VI. Equipment Required in Mobilization of Military Units, U. S. Army

Military Units	Personnel: Officers	Men	Animals	Vehicles	Guns (complete)	Railway Equipment: Pullmans	Coaches	Baggage	Box	Stock	Flat or Gondola	Total	Trackage (Feet)
Infantry Regiment	55	1,890	477	22		5	43	5	15	9	8	85	5,150
Cavalry "	54	1,284	1,438	26		8	28	8	25	72	9	150	7,850
Artillery " (Light)	45	1,170	1,157	32	24	9	23	9	25	58	46	170	8,675
" " (Horse)	45	1,173	1,571		24	10	24	10	25	78	47	194	9,830
" " (Mountain)	45	1,150	1,229		24	7	23	7	30	61		128	6,405
Engineers—Pioneer Battalion	16	502	165	12		2	12	2	10	8	4	38	2,110
Signal Corps—Field "	9	171	206	15		2	4	2	5	10	5	28	1,460
Infantry Division: 3 brigades infantry; 1 regiment cavalry; 1 brigade light artillery; 1 pioneer corps; 1 field battalion (signal corps); Wagon trains	736	22,285	7,660	775	48	46	487	45	245	383	301	1,507	82,265
Cavalry Division: 3 brigades cavalry; 1 reg't horse artillery; 1 battalion pioneers; 1 " signal corps; Wagon trains	458	10,259	12,231	414	24	63	218	63	210	611	137	1,302	77,190
Field Army							2,115	385	1,055	1,899	775	6,229	*Trains* 366

Since the above schedule was prepared, the infantry division for service abroad has been reorganized as follows:

Infantry Regiment	officers	103	men		3,652
Rifle Company	"	6	"		250

	STRENGTH
INFANTRY DIVISION.	
Headquarters	164
Machine-gun Battalion	768
Two Brigades of Infantry — each of two Regiments, and one Machine-gun Battalion of three Companies	16,420
Field Artillery Brigade — three Regiments, — and one Trench-mortar Battalion	5,068
Field Signal Battalion	262
Engineer Regiment	1,666
Train Headquarters and Police	337
Ammunition Train	962
Supply Train	472
Engineer Train	84
Sanitary Train, four Field Transportation Companies, four Ambulance Companies	949
Total	27,152

VII. THE AMERICAN RAILWAY ASSOCIATION

SPECIAL COMMITTEE ON NATIONAL DEFENSE

NEW YORK, May 8, 1917.

TO ALL RAILROADS:

Notice is hereby given that the railroads named herein have filed the following agreement subscribing to the action taken at the conference of railway executives in Washington, D. C., on April 11, 1917:

The undersigned railroad company subscribes to the following resolutions adopted at a conference of railway executives, held in Washington, D. C., on April 11, 1917:

WHEREAS, This meeting has assembled in response to an invitation from the Council of National Defense, and has had laid before it a resolution by that Council as follows, viz.:

"*Resolved*, That Commissioner Willard be requested to call upon the railroads to so organize their business as to lead to the greatest expedition in the movement of freight."

Now, therefore, be it

Resolved, That the railroads of the United States, acting through their chief executive officers here and now assembled, and stirred by a high sense of their opportunity to be of the greatest service to their country in the present national crisis, do hereby pledge themselves, with the Government of the United States, with the Governments of the several States and one with another, that during the present war they will coördinate their operations in a continental railway system, merging during such period all their merely individual and competitive activities in the effort to produce a maximum of national transportation efficiency. To this end they hereby agree to create an organization which shall have general authority to formulate in detail and from time to time a policy of operation of all or any of the railways, which policy, when and as announced by such temporary organization, shall be accepted and earnestly made effective by the several managements of the individual railroad companies here represented;

Resolved, That the following form of organization for all of the railways of the United States to coöperate with the Government in the conduct of the War be adopted:

1. That the whole problem of coöperation with the Government be committed to the present Special Committee on National Defense of The American Railway Association. This involves making the Commission on Car Service a sub-committee of the Special Committee, as has already been done with the Committees on Military Passenger Tariffs, Military Freight Tariffs, Military Equipment Standards, and Military Transportation Accounting.

2. That the Special Committee be enlarged by additions to a total of approximately 25 members.

3. That an Executive Committee, selected from the 25 members of the Special Committee on National Defense, consisting of the Chairman of the Special Committee, who shall also be Chairman of the Executive Committee and four other members to be selected by him, be created, such Executive Committee to sit in Washington in frequent or, if necessary, continuous session.

4. That Mr. Daniel Willard, as Chairman of the Advisory Commission of the Council of National Defense, be *ex officio* a member of the Executive Committee.

That the Interstate Commerce Commission be invited to designate one of its members to be *ex officio* a member of the Executive Committee.

5. That the railways agree to the direction of the Executive Committee of five in all matters to which its authority extends, as expressed in the resolution heretofore adopted, and to which we hereby subscribe; and that the General Secretary of The American Railway Association be instructed to secure the execution by signature of all American railways.

APPENDIX IX

Operation Data

Notes and Tables I to VI

I. Technical Associations of Railroad Officers. United States of America

Air Brake Association.
American Association of Railroad Superintendents.
American Electric Railway Engineering Association.
American Railroad Master Tinners, Coppersmiths and Pipe Fitters Association.
American Railway Bridge and Building Association.
American Railway Engineering Association.
American Railway Master Mechanics Association.
American Railway Tool Foremen's Association.
Association of Railway Electrical Engineers.
Association of Railway Telegraph Superintendents.
Bureau for the Safe Transportation of Explosives and other Dangerous Articles.
Car Foremen's Association.
International Railroad Master Blacksmiths Association.
International Railway Fuel Association.
International Railway General Foremen's Association.
Maintenance of Way Master Painters Association.
Master Boiler Makers' Association.
Master Car and Locomotive Painters' Association of the United States and Canada.
Master Car Builders' Association.
Railway Fire Protection Association.
Railway Gardening Association.
Railway Real Estate Association.
Railway Signal Association.
Road Masters' and Maintenance of Way Association.
Train Dispatchers' Association of America.
Traveling Engineers' Association.

II. International Railway Congress, Berne, 1910. Conclusions as to the Use of Statistics

Proceedings, Vol. III, XIV, 304

Subject to the particular conditions affecting railroad accounting resulting from control of, or financial interest in, the railways by the State,

The Congress finds that:

1. Statistics, to be of value for operating purposes, should be made available for the operating officers at the earliest practicable date after the performances of the services for a given period.

2. To be of greater value from an economical operating standpoint, statistics prepared for operating officers should include only such costs as are directly in-

curred by the officer interested, and all indirect costs should be separated therefrom.

3. No one line of statistics should be exclusively relied upon, but statistics reflecting all factors essential to revenue and costs should be prepared and properly considered.

4. The respective statistics of railway administrations are based on principles suited to their varying conditions, but the circumstances and conditions of working necessarily differ in different countries, and it is practically impossible to arrive at an absolutely uniform system of operating statistics applicable alike to all countries.

5. It is, however, desirable to encourage efforts toward unification of railway statistics, at least so far as the main elements of railway working are concerned, to the extent to which this is possible, having regard to the necessities of each country.

III. Division of the Transportation Department

Railroads over 400 Miles in Length. United States and Canada, 1917

ROADS WITH DIVISION SUPERINTENDENTS

Average Length of Division, Miles	Number of Divisions	Per Cent. of Total
Under 200	39	7
200–300	141	23
300–400	108	16
400–500	190	32
500–600	85	14
600–700	36	6
700–800	4	
800–900	4	2
1120	2	
Total	609	100

ROADS WITH TWO GENERAL SUPERINTENDENTS

800 to 1000 miles each	11	
1000 " 1500 " "	19	
1500 " 2000 " "	3	
2000 " 2500 " "	6	
Total	39	

ROADS WITH TWO GENERAL MANAGERS

2500 to 3000 miles each	1	
3000 " 4000 " "	2	
4000 " 4500 " "	4	
6464 "	1	
Total	8	

IV. Summary of Employees, by Class and per 100 Miles of Line Operated, June 30, 1914

From Report of Interstate Commerce Commission

Class of Employees	Eastern District Number	Eastern District Per 100 mi.	Southern District Number	Southern District Per 100 mi.	Western District Number	Western District Per 100 mi.	United States Number	United States Per 100 mi.
General officers	1,825	3	1,241	2	2,674	2	5,740	2
Other officers	4,271	7	2,819	6	4,063	3	11,153	4
General office clerks	40,716	63	12,375	25	34,015	24	87,106	34
Station agents	14,786	23	8,443	17	15,918	11	39,147	15
Other station-men	83,803	129	28,449	57	51,351	36	163,603	64
Enginemen	29,773	46	10,373	21	21,875	16	62,021	24
Firemen	31,237	48	10,908	22	22,814	16	64,959	25
Conductors	23,161	36	8,945	18	16,095	11	48,201	19
Other trainmen	66,402	102	22,107	45	48,300	34	136,809	53
Machinists	32,116	49	7,499	53	16,853	12	56,468	22
Carpenters	29,065	45	16,304	13	27,554	19	72,923	28
Other shopmen	105,699	163	52,700	106	97,734	69	256,133	100
Section foremen	15,502	24	8,110	16	21,365	15	44,977	18
Other trackmen	113,404	174	58,716	118	165,331	117	337,451	132
Switchmen and watchmen	24,910	38	4,804	10	8,159	6	37,873	15
Dispatchers and operators	20,156	31	6,336	13	13,972	10	40,464	16
Floating equipment	9,599	15	243		3,177	2	13,019	5
Miscellaneous laborers	95,410	147	38,358	77	98,481	62	232,249	91
Total	741,835	1,143	298,730	601	669,731	792	1,710,296	667

V. Distribution of Employees by Class of Service, 1914

From Report of Interstate Commerce Commission

Class I and Class II Roads

Class of Service	Eastern District Number	Eastern District Per 100 miles	Southern District Number	Southern District Per 100 miles	Western District Number	Western District Per 100 miles	United States Number	United States Per 100 miles
Maintenance of Way	162,427	257	85,809	183	198,673	144	446,909	180
Maintenance of Equipment	169,173	268	77,595	166	124,452	90	371,220	150
Traffic	8,094	13	5,014	11	8,708	6	21,816	9
Transportation	316,609	502	111,362	238	192,333	140	620,304	251
General	20,621	34	8,910	19	24,742	18	54,273	22
Outside operations	19,350	31	2,915	6	10,868	8	33,133	13
Unclassified	41,725	66	2,245	5	103,768	76	147,738	60
Total	737,999	1,171	293,850	628	663,544	482	1,695,393	685

PROPORTION OF CLASSES TO TOTAL NUMBER OF EMPLOYEES

Class	Eastern District	Southern District	Western District	United States
Maintenance of Way	22 per cent.	29 per cent.	30 per cent.	26 per cent.
Maintenance of Equipment	23 per cent.	26 per cent.	18 per cent.	22 per cent.
Traffic	1 per cent.	2 per cent.	1 per cent.	1 per cent.
Transportation	43 per cent.	38 per cent.	29 per cent.	37 per cent.
General	3 per cent.	3 per cent.	4 per cent.	3 per cent.
Outside operations	2 per cent.	1 per cent.	2 per cent.	2 per cent.
Unclassified	6 per cent.	1 per cent.	16 per cent.	9 per cent.

VI. Railway Employees in Great Britain and Ireland, 1910 (Exclusive of Heads of Departments)

Board of Trade Report

Employment	Number	
Capstan-men	Men, 1,421	
	Boys, 140	1,561
Car-men and Van Guards	Men, 18,382	
	Boys, 6,604	24,986
Carriage-cleaners	Men, 6,572	
	Boys, 286	6,858
Carriage and Wagon Examiners		3,811
Checkers	Men, 9,112	
	Boys, 77	9,189
Chockers, Chain-boys and Slippers	Men, 288	
	Boys, 271	559
Clerks	Men, 61,361	
	Boys, 9,044	70,405
Engine-cleaners	Men, 13,912	
	Boys, 4,267	18,179
Engine-drivers and Motormen		27,330
Firemen		25,419
Gate-keepers		3,543
Greasers	Men, 943	
	Boys, 753	1,696
Guards (goods) and Brakesmen		15,339
Guards (passenger)		8,239
Horse-drivers		1,159
Inspectors — Permanent Way		1,029
Others		8,603
Laborers	Men, 54,981	
	Boys, 1,333	56,314
	Forward,	284,219

Employment	Number	
	Forward,	284,219
Lamp-men and Lamp-lads	Men, 1,655	
	Boys, 418	2,073
Loaders and Sheeters		4,274
Mechanics and Artisans	Men, 78,389	
	Boys, 8,294	86,683
Messengers	Men, 1,124	
	Boys, 2,468	3,592
Number-takers	Men, 1,252	
	Boys, 671	1,923
Permanent-Way-men		66,305
Pointsmen		708
Policemen		2,130
Porters	Men, 53,388	
	Boys, 4,501	57,889
Shunters		13,281
Signal and Telegraph Wiremen		3,905
Signalmen		28,653
Signal-box lads		1,894
Station-masters		8,684
Ticket Collectorsand Examiners		3,904
Watchmen		1,151
Yardsmen		1,299
Miscellaneous	Men, 33,620	
	Boys, 2,563	36,183
		608,750
Boys (under 18) about 7 per cent.		41,690
Men		567,060
Line-mileage		23,389
Av. no. employees per 100 m. of line		2,603
" " exclusive of Car-men and Van Guards		2,496

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