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THE ECONOMICS

OF

RAILROAD CONSTRUCTION

BY

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THE
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INTRODUCTION.

Owing to the diversity of opinion existing among railroad men as to the proper scope of a book on railroad economics, a word of introduction is necessary. Railroad economics, in its broadest sense, covers the entire subject of railroad engineering, from the most simple feature of railroad surveying to the weightiest questions of railroad practice or legislation which could be brought before the Interstate Commerce Commission, Congress, or the United States Supreme Court. While it is of course desirable that an engineer should have as broad a knowledge as possible of every phase of railroad management and legislation, it should not be forgotten that his primary work is that of construction, maintenance, and operation. If the railroad engineer should develop into the railroad president, the larger questions must be answered, but even in such a case an encyclopedia of railroad science would not cover the ground with which he should be familiar.

It is assumed that those who read or study this book are already familiar with the mechanical processes used in railroad surveying and construction; that they know how to survey a line (when the economic questions of its location have been decided), and how to build a line as thus laid out. Of course many of the simpler economic principles will have been included in any good course in surveying and construction. But such courses do not usually include an exhaustive exposition of the reasons *why* certain grades should be adopted, or *why* a certain large expenditure for a tunnel, bridge, or other special construction may (or may not) be justifiable. The justification of improvements by changes in alinement also comes within the scope of the engineer. The constructing engineer should also know enough of the work of operation to understand the effect on operation of constructive details. This requires a knowledge of operating expenses, locomotive and car construction, train-resistance, and the operation of heavy trains on grades. Even then the constructive engineer is not equipped for his work until he has dipped into law and finance—until he understands the legal method of organization and the methods of the world of railroad finance.

Rising still higher, the railroad man is sometimes confronted with an apparent conflict between a policy which would best serve the public, and a policy which would afford greater immediate profit to the stockholders. Probably such conflicts are more apparent than real. History has invariably shown that the prosperity of a railroad is closely bound up with that of the community which it serves, and that in the long run the interests of the stockholders are best promoted by policies which give the best possible service to the public.

This book is therefore written from the standpoint of the constructing or operating engineer. The railroad lawyer or legislator would find little or nothing in it which he can use, and much in which he is not interested. Even the professor of social economics will find that it is written from the technical standpoint rather than from the social viewpoint, and yet (as before mentioned) it will be emphasized that the best social standpoint will also prove to be the best technical standpoint.

The practicable size of this book has also been considered. An adequate discussion of railroad legislation alone would more than fill a book of this size. Therefore legislation and kindred subjects are only considered very briefly, and almost exclusively as they affect questions which must be answered by a railroad engineer.

The author wishes to acknowledge his indebtedness to many engineers throughout the country who have furnished him with some very valuable technical information. The sources of such information have each been indicated during its discussion.

Those familiar with recent railroad literature, especially the books dealing with railroad legislation, the regulation of rates, etc., will appreciate the author's indebtedness to some of them. The chapters of this book dealing with kindred subjects attempt to give an abridged outline of some of the most salient features of these valuable additions to railroad science. For more complete discussions the student should read the following: "Railway Legislation in the United States," by Dr. B. H. Meyer; "Restrictive Railway Legislation," by H. S. Haines; "American Railway Transportation," by E. R. Johnson; "The Elements of Railway Economics," by W. M. Acworth; "Railroad Transportation," by A. T. Hadley; and "American Railroad Rates," by W. C. Noyes.

PART I.

FINANCIAL AND LEGAL ELEMENTS OF THE PROBLEM.

CHAPTER I.

RAILROAD STATISTICS.

1. **Mileage.**—A study of the growth of railroad mileage during a period of years will reveal many instructive features of railroad progress. In the following chapter will be given several tables of statistics showing the growth of the railroad industry, especially during later years. From such tables it is possible to draw conclusions, regarding the present status of railroad business and its probable future growth, which will be of considerable value to the railroad engineer in understanding many of the problems which must be solved. But it should not be forgotten that the proper interpretation of statistics is not easy, and that wrong conclusions may readily be drawn from them. An endeavor will be made to point out some of the legitimate conclusions which these statistics indicate. In Table I is given the mileage in the United States for each year from 1870 to 1904, the increase for each year, the number of miles of line per 100 square miles of territory, the number of miles of line per 10,000 inhabitants, and the total railway capital per mile of line. The figures for the year 1888 and later are taken from the reports of the Interstate Commerce Commission. Those for previous

years have been taken from various sources, chiefly the annual issues of Poor's Manual. The figures given in the later issues of Poor's Manual do not agree exactly with those from the Interstate Commerce Commission, although the agreement is sufficiently close for any deductions which we may here wish to draw from the figures. It should be noted that the "number of miles of line" does not consider whether the road has one track, two, three, or four, nor that a mile of line in one place may be worth ten or twenty times a mile of line in some other place. The growth of the mileage may be most readily studied by an inspection of Fig. 1. The steeper the line, the more rapid has been the growth in mileage. The annual increase and its fluctuations are more readily seen in Fig. 2. For several years after the "boom" times of 1870 to 1873 but little was done, until another boom began about 1878–9. This culminated in 1882 and dropped suddenly in 1884–5. After the panic year of 1893 but little was done until 1898–9. Since that time there has been an almost steady *increase* in the number of miles added each year. It is hardly possible that this *increase* in growth can be long maintained. A steady growth each year is about as much as could be expected, while a decrease for a period of years is quite probable.

The "number of miles of line per 100 square miles of territory" is shown graphically in Fig. 3. Since the area considered is constant, the number constantly increases The rate of growth is indicated by the steepness of the line or by the *differences* which are given in column 4 of Table I and are indicated graphically in Fig. 3. These vary approximately as the increase in the mileage. In column 5 of Table I is shown the "number of miles of line per 10,000 inhabitants." A glance at that column will show at once that for the last fifteen years the number is very nearly constant. The number reached a maximum in

1893. The check in railroad building caused by the panic of that year caused a gradual reduction in the ratio, which meant that the population was growing faster than the building of railroads. This tendency was not checked until 1899. Since that year the prosperity of the country has so increased that it can afford more miles of railroad per 10,000 inhabitants.

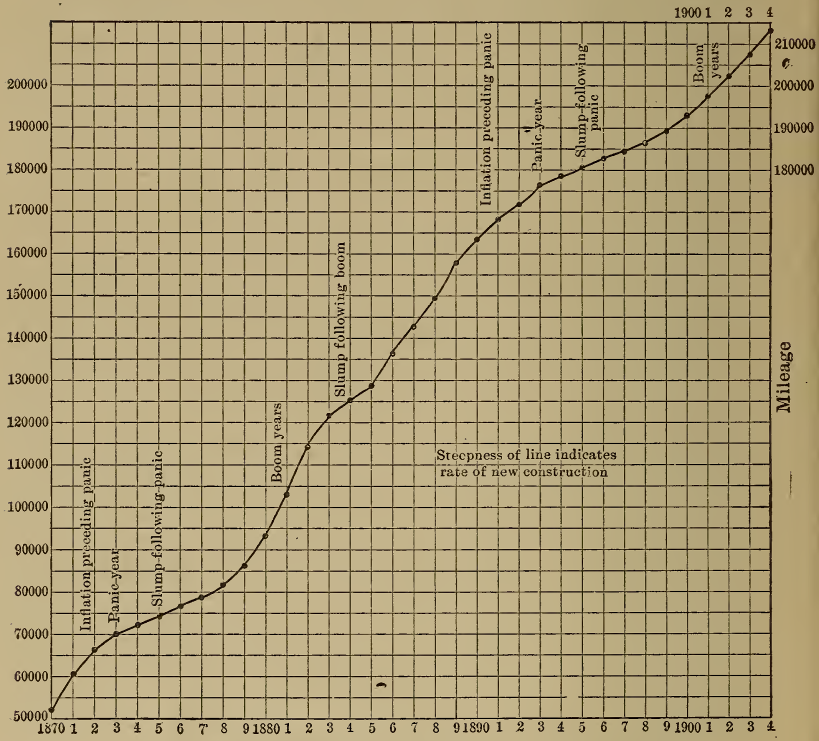


FIG. 1.—Total railroad mileage in the United States.

The "total railway capital per mile of line" has remained fairly constant. Disregarding the value given for 1870, which is of somewhat doubtful accuracy, the remaining figures are marvelously uniform. This is all the more

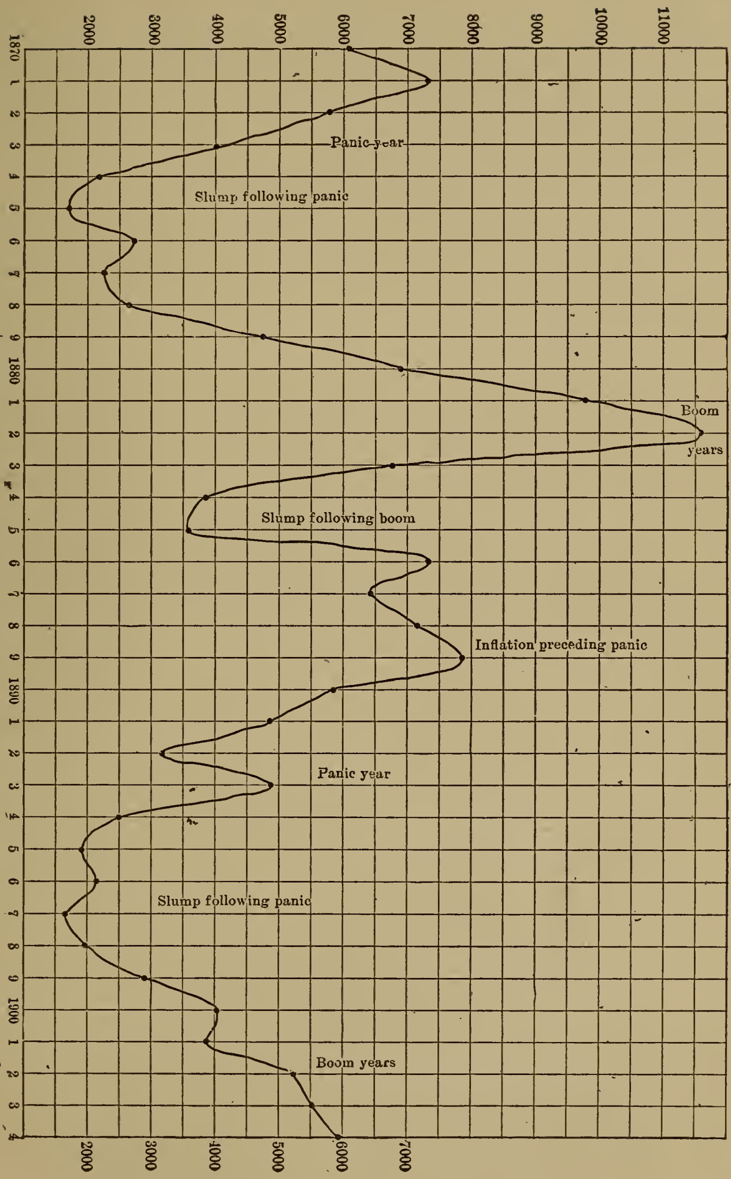


Fig. 2.—Increase in railroad mileage per year.

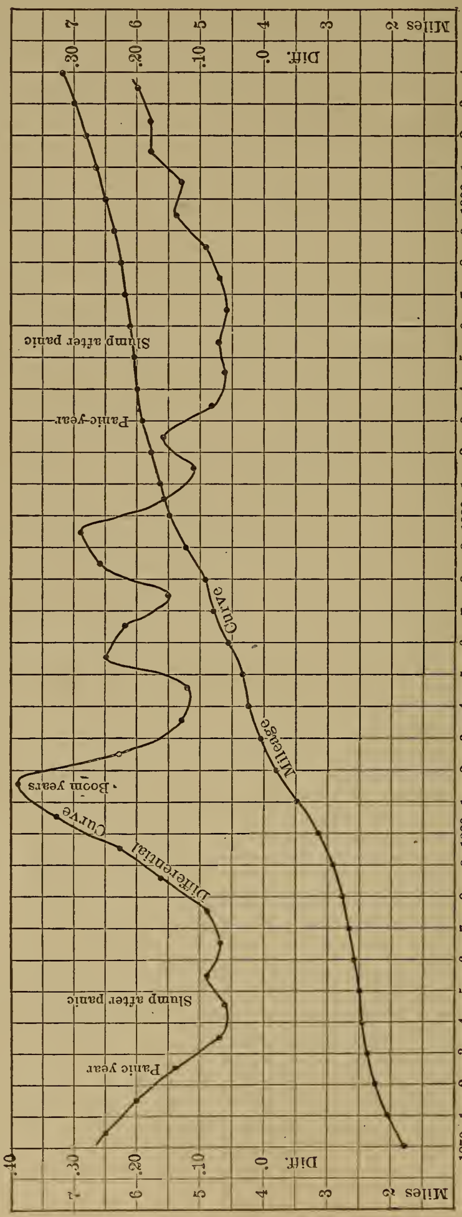


FIG. 3.—Miles of line in the United States per 100 square miles of territory.

Table I.—Railroad Statistics.

1	2	3	4		5	6
Year.	Mileage.	Annual increase.	Number of miles of line per 100 square miles of territory.	Diff.	Number of miles of line per 10,000 inhabitants.	Total railway capital per mile of line.
1870	52 914	6,070	1.78	.25	13.72	$44,255
71	60,293	7,379	2.03	.20	15.18	59,726
72	66,171	5,878	2.23	.14	16.19	55,116
73	70,268	4,097	2.37	.07	16.71	57,136
74	72,383	2,117	2.44	.06	16.76	60,944
1875	74,096	1,711	2.50	.09	16.74	61,534
76	76,808	2,712	2.59	.07	16.87	60,791
77	79,089	2,280	2.66	.09	16.94	60,699
78	81,776	2,629	2.75	.16	17.08	58,916
79	86,497	4,746	2.91	.23	17.65	58,070
1880	93,349	6,886	3.14	.33	18.61	58,624
81	103,145	9,796	3.47	.39	20.06	60,645
82	114,713	11,568	3.86	.23	21.77	60,830
83	121,454	6,741	4.09	.13	22.51	61,592
84	125,379	3,825	4.22	.12	22.71	60,886
1885	128,967	3,588	4.34	.25	22.83	60,897
86	136,338	7,371	4.59	.22	23.61	60,564
87	142,776	6,438	4.81	.15	24.19	58,093
*1888	149,902	7,126	4.96	.26	24.87	59,392
89	157,759	7,857	5.22	.29	25.63	58,775
1890	163,597	5,838	5.51	.16	26.05	60,340
91	168,403	4,806	5.67	.11	26.26	60,942
92	171,564	3,161	5.78	.16	26.22	63,776
93	176,461	4,898	5.94	.08	26.43	63,421
94	178,709	2,247	6.02	.06	26.25	62,951
1895	180,657	1,949	6.08	.07	26.03	63,206
96	182,777	2,119	6.15	.06	25.84	59,610
97	184,428	1,652	6.21	.07	25.60	59,620
98	186,396	1,968	6.28	.09	25.41	60,343
99	189,295	2,898	6.37	.14	25.35	60,556
1900	193,346	4,051	6.51	.13	25.44	61,490
01	197,237	3,892	6.64	.18	25.52	61,531
02	202,472	5,234	6.82	.18	25.76	62,301
03	207,977	5,505	7.00	.20	26.03	63,186
04	213,904	5,927	7.20		26.34	64,265

* For 1888 and later, figures taken from reports of Interstate Commerce Commission. Earlier reports less reliable and accurate.

surprising when we consider that every mile of railroad is far better and more valuable than it was twenty-five or thirty years ago. Evidently the capitalization is now a truer measure of actual worth than it was many years ago. If we multiply the corresponding numbers of columns 5 and 6, and divide by 10,000, we would get "the total railway capital per inhabitant," which will vary from a minimum of about $61 per inhabitant in 1870 to $169 in 1904. It may also be noted that one of the highest values of the total railway capital per inhabitant ($168) occurred immediately before the financial crash of 1893. For some reason the values of "total railway capital per inhabitant," computed by the above method, are somewhat larger than the corresponding values as given in Table II, which are taken from U. S. Census Reports. The differences are not sufficiently large to alter any conclusions we may wish to draw from them.

2. **Capitalization.**—Deferring until Chapter III an analysis of railway capital from the financial standpoint, it is instructive to note the total value of railway property and its relation to the total national wealth. In Table II is given for decennial periods the total national wealth, the wealth per inhabitant, and the corresponding average figures for railway property.

TABLE II.—NATIONAL WEALTH AND RAILWAY CAPITAL.

Year.	Total national wealth, millions.	Population.	Wealth per capita.	Total railway capital, millions.	Railway capital per capita.
1850	$ 7,136	23,191,876	$ 308	$ 297*	$ 13
1860	16,160	31,443,321	514	1,156*	36
1870	30,069	38,558,371	780	2,041*	53
1880	43,642	50,155,783	870	5,108	102
1890	65,037	62,622,250	1036	9,437	151
1900	94,300	75,568,686	1248	11,491	152

* Cost of construction.

It affords some idea of the magnitude of the railroad business of the country to note that if the total railway capitalization (stocks and bonds) in 1900 were divided equally among the total population, every man, woman, and child would have railroad securities of a par value of \$152. It will be shown later that the "commercial value" of all the railroads for 1904 was about 85% of their par value.

3. **Public service of railways.**—A few statements regarding the actual service rendered by railways will permit the student to better appreciate the influence which railroads have on our civilization. The statistics for the year ending June 30, 1904, may be considered as typical. The number of passengers reported as carried was 715,419,682, which means an *average* of nearly nine rides per capita. The average ride was over 30 miles, for which an average revenue of 2.006 cents per mile was received. The enormous volume of "commutation-ticket" mileage is responsible for the reduction of this figure from the usual charge of 3 cents per mile. The average number of passengers in a train was 46, with average receipts of \$1.14 per passenger-train mile.

The "number of tons carried one mile" was 174,522,098,577. Dividing this by the population, we have 2309 ton-miles per capita. This means that every man, woman, and child would be responsible (if all were equally responsible) for the haulage of 2309 ton-miles or 23 tons of freight a distance of 100 miles. The average number of tons of freight in a train was 308, which was carried at an average charge of 0.78 cents per ton per mile. The revenue per freight-train mile was \$2.44. The average revenue per train-mile for all trains was \$1.94, while the average cost was \$1.31. The passenger revenue comprised 22.50% of the total, and the freight 69.82%. The remaining 7.68% is divided between mail, express, and other miscellaneous earnings. The "total earnings from operation" were $1,975,174,091, which was nearly 15% of the total capitalization. These earnings represent over $24 per capita. In considering this large payment per capita, it should be realized that a considerable proportion of the cost of every ton of coal and, perhaps in lesser degree, of almost every article of manufacture and of farm and mineral products consists of the cost of transportation, which is paid indirectly to a dealer, if it is not paid directly to the railroad company.

4. **Employees.**—1,296,121 employees were carried on the rolls on June 30, 1904, or an average of 6.11 per mile of line. There were paid to these employees $817,598,810, which is over 41% of the gross earnings from operation, or 61% of the total operating expenses. This number of employees represents nearly one-sixtieth of the population. Probably one-twentieth of the population was supported by these earnings. When we consider the number of locomotive shops, car shops, bridge shops, and factories of various kinds whose output is consumed in whole or in part by the railroads of the country, it is probably true that one-fourth of the entire population live on wages furnished directly by the railroads or by industries which are chiefly supported by railroads.

5. **Accidents.**—During the year ending June 30, 1904, the numbers reported as killed and injured were 10,046 and 84,155 respectively. This is an average of one person killed every 52 minutes and one person injured every 6 minutes. While this statement looks very bad, the railroads are not altogether responsible. Of the total 10,046, only 441 (a little over 4%) were passengers; 3632 (about 36%) were employees; and the remainder, 5973, were "other persons," of whom 5105 (over 50% of the total) were "trespassers," which includes suicides. Therefore the ailroads cannot be held responsible for over one-half of

those deaths. Of the 84,155 persons injured, the number of passengers was 9111, or about 11%, and the number of employees 67,067, about 80%. About one-sixth of the deaths, and about one-eighth of the injuries, of passengers were caused by "jumping on or off trains, locomotives, or cars." In nearly all of such cases the passengers were alone responsible.

In the face of such a death-list, it is hard to realize the very small probability of an injury or death occurring to any passenger during any one ride. The "number of passengers carried one mile" for 1904 equaled 21,923,213,536. Dividing this by 441, the number of deaths of passengers, we have over 49,700,000, the number of passenger-miles for each death. Again, dividing 21,923,213,536 by 9111, the number of passengers injured, we have over 2,400,000 as the number of passenger-miles for each injury. The practical meaning of such figures is that, in the language of the theory of probabilities, the "chances are even" that if a passenger were to ride continuously at the rate of 40 miles per hour, or 350,640 miles per year, he would ride for 142 years before being killed, or about 7 years before being injured. But, as a matter of fact, no one uses the railway for a distance of 350,000 miles per year, or even any large proportion of it. A better way of considering the probabilities would be to say that, since there were 49,700,000 passenger-miles for each death, a trip of say 100 miles would involve a risk of one in 497,000 that it might result in death, assuming that the operation of the railroad during that trip was neither more nor less hazardous than the average railroad operation. A similar figure could be computed to determine the probability that any given trip might result in an injury to any given passenger. It should not be forgotten that during the year 1904 a far greater number of passengers were killed than during any year for the previous 16 years. In 1895 the number of passengers killed was only 170, which was less than 40% of the figure for 1904. Although the amount of railway business was far greater in 1904 than in 1895, and we might expect some increase in the fatalities, yet the probabilities were far less in 1895 than in 1904.

There has been much discussion of the subject of accidents as an element in railroad economics. Some economists have endeavored to place a financial value on accidents and to determine how much money could profitably be spent to avoid the danger of accidents. While no one will deny the justification of spending a reasonable amount of money to avoid the danger of an accident due to some specific cause, the question always remains, How much actual lessening of danger will be accomplished by any reasonable or practicable expenditure of money? Certain classes of improvements are demonstrably justifiable, as, for example, the elimination of grade highway-crossings, especially on a road of heavy traffic. A more doubtful question occurs when it is proposed to reduce some sharp curvature when passing through a mountainous region where the view of the track is obstructed for any great distance. In such a case the practical question is not the lessening of danger by the elimination of *all* curvature, which would probably be financially, if not physically, impossible, but the lessening of danger by the use of less curvature rather than more. It may usually be shown that the lessening of the probability of accidents, due to such reductions of curvature as are practicable, is so small that such a consideration alone will not justify the expenditure of any appreciable amount of money to accomplish the result.

6. Use of statistical averages.—The student should be cautioned against an improper use of the statistical averages given in this chapter and in Chapter VI. They should be considered somewhat in the same light as a composite photograph of a group of men. The composite photograph cannot be considered as a correct photograph of any one, unless he happens to have the average features. The above averages regarding wealth per capita, railway capital per capita, and the average payment to railroads per capita should not be assumed to have any application to any particular case. For example, the student should not consider that the average annual payment as given for 1904—$24 per capita—would represent the earnings of any proposed railroad from its tributary population, unless there is good reason to believe that the particular territory in question is a fair average sample of the whole country. And even in this case the determination of the "tributary population" is not easy. Such a figure has its value to give the student a rough idea of railroad earnings and railroad operation, but he should know that such figures cannot be depended on, except as a rough check on computations which have been more carefully made from local considerations.

CHAPTER II.

THE ORGANIZATION OF RAILROADS.

7. Economic justification of railroad projects.—Social economists and railroad capitalists are apt to consider the desirability of constructing the railroad from two different points of view. The social economist considers chiefly the effect of the road in building up the wealth of the community through which it passes. The railroad capitalist looks on the whole project as a business enterprise and as a project for making money. It may readily be demonstrated that in the long run the two objects are really identical and require identical methods to arrive at the result. Of course there are cases where a railroad enterprise has been launched for the purpose of blackmailing another competing line, and there are likewise many cases where the promoters intend to unload their securities at the first favorable opportunity, and have no thought of the future history of the road or the ultimate value of its securities. Disregarding such methods, which may be characterized as gigantic swindles, we may consider that the normal project of constructing a railroad consists in developing a transportation agency which will not only increase the wealth of the country, but which will itself derive profit from the increasing wealth of the country, and that the wealth of each will increase the wealth of the other almost without definite limit. The prosperity of the railroad project and of the country through which it passes will be mutually dependent. We may therefore disregard at the outset the idea that any policy of construction or management which would be beneficial to the road will be injurious to the community. Of course it may readily happen, and instances are numerous, especially with roads of considerable length, that the cities and industries of one section of the road will be built up at the expense of those of another, and that the policy which is really the most advantageous for the railroad as a whole may be injurious to the interests of a small section of the country through which it passes. Even here, we should not forget that the railroad has lost something, although it may have gained more. It has lost a portion of traffic which it might have obtained by the building-up of the section which has been slighted and perhaps really injured.

The organization of a railroad always begins essentially with the idea that a road built through a certain stretch of country will be a paying investment. It also proceeds on the basis, which is often not realized, that it should and will be a paying investment to the original promoters. It is unfortunately true that but few railroads which are old enough to have had a history have escaped a receivership, or at least serious financial difficulties, at some time in their history. Nevertheless, the fundamental idea of the enterprise is that it shall be financially profitable to the promoters of the road.

8. Basis of ownership of railroad property.—A railroad enterprise is fundamentally different from a large majority of industrial enterprises. A factory is usually built and equipped by means of money which is directly furnished by the promoters of the enterprise. It may be that a mortgage will be placed upon the buildings and machinery, but this will be only a small proportion of the entire capitalization needed to launch the enterprise. On the other hand, railroads are built very largely on the proceeds of borrowed money, which is secured by bonds of the road. Although the amount of nominal capital may be, and generally is, equal to the issue of bonds, the amount of *paid-in capital* is frequently but a very small proportion of the bond issues. In the early history of railroading, when the whole country was ripe for such work, when railroad facilities were very greatly needed, and when communities became convinced, as was actually true, that almost any railroad would ultimately be a paying investment, it was generally possible to borrow a very large proportion, if not all, of the money required for an enterprise on the basis of the bonds. In theory the capital stock of the road should represent the great bulk of its cost, and the bond issue, if any, should only represent the debt which must be placed on the property after the capital is subscribed in order to complete the work, but in this country the practice seems to have gone almost to the other extreme. Roads are usually bonded to the highest possible limit, while the amount of money actually furnished on capital stock represents the margin between the necessary cost and the confidence of the public in the enterprise as a whole.

The English plan of building railroads appears to have been very different. The railroad charters were modeled largely on the charters of the previously established turn pikes. The turnpike companies did not own their roads, but merely owned the right to operate them and to charge toll for their use. Following this idea, an English railroad cannot mortgage its property in the sense in which it can be done in this country. They may issue debenture bonds, which are merely a lien on the *income* of the road, but which will not permit the road to be sold under foreclosure, even if the road should default the payments of interest. In this country the mortgage carries with it the right to demand the sale of the road, under a certain legal form of procedure, if the obligations imposed by the bonds are not fulfilled.

9. **Charters.**—It has been declared that charters are not laws, but exemptions from the laws. The term charter, as applied in the time of the Middle Ages, represented a special privilege granted by the king to do some act, to collect some revenue, or to enjoy certain privileges which were not granted to the people in general. When the turnpike roads and canals were first authorized, each was granted a charter which gave to each company certain peculiar rights and privileges. When railroads were first constructed, they were authorized by special legislation in a somewhat similar manner. To a considerable extent this is essential, since the railroads necessarily must be enabled to exercise the right of eminent domain. The fact that some railroads have been built with little or no difficulty, so far as obtaining right-of-way is concerned, the right-of-way having been donated, and with extensive tracts of lands thrown in as a bonus, does not weaken the general statement that a railroad would be helpless unless it were enabled to exercise the right of forcing its way wherever engineering requirements shall dictate. But as the number of railroad projects multiplied, the forms of charters which were granted were frequently simplified by referring to the terms of a charter which had been previously granted. This gradually led to the adoption of general railroad laws, which thereby changed the granting of a charter into a mere matter of routine procedure instead of a special legislative act. The various States have been gradually coming into line in this respect, so that roads which are constructed in the future will be authorized by a more nearly uniform legal procedure. An examination of the charters on which the largest railroad systems of the present day rest will show a very curious situation with respect to many of them. For example, the Northern Pacific Railroad, with a mileage of over 5600 miles, is operated on the basis of a charter which was granted for

the construction of an unimportant line in Wisconsin. Even this little line was not built, but the charter was slightly amended by the State Legislature, and on the basis of this insignificant charter this great system was built and is operated.

10. General railroad laws.—The earlier charters of roads usually began with a preamble reciting that there was a public necessity for the project. The general railroad laws follow this idea to the extent of requiring the promotors of an enterprise to present evidence before a railroad commission that the proposed road is a public necessity and that it has "sufficient utility to justify the taking of private property." Whenever there is any limitation regarding railway rates, the limitations have usually been placed so high that they have never been invoked. Sometimes the Legislature has been empowered to reduce rates without the consent of the company, but this provision is usually accompanied by the proviso that such action shall not be taken if it can be shown that it would thereby reduce the net profits of the road below some limit, say 10% per annum. Such a limitation usually renders the provision of no effect. Many charters have contained the provision that if the net profits of the road shall exceed a certain per cent all excess profits of the road shall be turned over to the State. It is probably true that no State has ever profited in this fashion, since the astute railroad manager would see to it that if the profits should ever show a tendency to go beyond the limitation, the money would be spent in improvements to the road. One of the finest railroads in the country is subject to such a limitation. Its excess profits have therefore been spent in this fashion, with the result that the added conveniences and facilities have still further increased its business, until the road is now one of the most gilt-edged railroad properties in the country.

The number of incorporators required varies in the different States, only two or three being required in several States, while twenty-five are required in some others. The minimum amount of capital stock is frequently specified as $10,000 per mile of road. An affidavit that some percentage, say 10% of the total capital stock, has actually been paid in cash is required in many States. Some charters limit the corporate existence to some definite period, such as 50 or 99 years. A map which shows the line of the road with more or less definiteness must be filed with the secretary of state, and it is sometimes required that a map showing the route through each county must be filed with the county clerk of that county. Many other specifications regarding the method of constructing the road, details regarding construction of rolling stock, such as safety appliances, the protection of highway crossings, etc., are required by the general railroad laws of various States. For a brief but comprehensive compilation of these, the reader is referred to "Railway Legislation in the United States," by Dr. B. H. Meyer.

11. General railroad law of the State of New York.—Some of the principal features of the general railroad law of the State of New York are quoted as a sample of one of the best and most equitable of such laws. The number of railroad incorporators may be fifteen or more. They shall file a certificate which shall state the name of the corporation; the number of years it is to continue; the kind of road; its length and termini; the name of each county in which any part is to be located; the amount of capital stock (not less than $10,000 per mile or, with narrow gauge, $3000), and the number of shares of stock. If the capital stock is to consist of common and preferred stock, the rights and privileges of the preferred stock over the common stock must be clearly stated. It must have at least nine directors, and the name and post-office address of each of the incorporators, with the number of shares of stock to which he subscribes, must be stated. One of the most important provisions against irresponsible projects is that an affidavit must be made by at least three of the directors that at least 10% of the minimum amount of capital stock required by law has been subscribed and paid in cash. A railroad corporation, after being duly organized, has the power to enter upon any lands in order to make any necessary surveys, but is subject to liability to the owner for all damage done; it is also authorized to acquire property which may be needed, and, if necessary, to acquire such property by condemnation proceedings. It may construct the road across, along, or upon any stream, watercourse, highway, plank road, turnpike, or across any of the canals of the State which the route of its road shall intersect or touch. This last provision, as well as the other provisions here given, is subject to modifications by special laws which apply particularly to the crossing of highways and canals. It may make a junction with any railroad which it may reach or cross, and may even compel, if necessary, the connecting road to allow suitable turnouts, sidings, and switches to be put in. The corporation may "take and convey passengers and property on its railroad by the power or force of steam or of animals or by any mechanical power, except where such power is specially prescribed in this chapter, and to receive compensation therefor." This virtually means that roads of any kind, whether the cars are propelled by steam, electricity, or even horse-power, are authorized to convey "persons and property" which includes freight. This disposes of the question of the authority of electric roads to carry freight, which is the subject of contention and legislation in other States. The corporation is also authorized to borrow money and to issue bonds for its security without any definite limitation of the amount, except that such a measure must have the consent of the State Board of Railroad Commissioners and of the stockholders owning at least two-thirds of the stock. Work must be begun within five years, and during that time at least 10% of the amount of capital must be expended. If the road is not finished and put in operation within ten years from the time of filing the certificate of incorporation its corporate existence and powers shall cease. The corporation is required to make a map and profile of the road adopted by it in each county through which it passes, and file a copy in the office of the county clerk. Written notice must be given to the actual occupants or owners of the lands over which it passes regarding the time and place of filing the map and profile. Such occupant or owner may within fifteen days give a ten days' written notice of an application to a Justice of the Supreme Court. The Justice may appoint three disinterested persons, one of whom must be a practical civil engineer, who shall pass upon the question of a proposed alteration in the line. The law is quite elaborate regarding the hearing of any plea for a proposed alteration of the line, with rules regarding appeals, etc. The maps filed with the railroad commission must show "length and direction of each straight line; the length and radius of each curve; the point of crossing of each town and county line, and the length of line of each town and county accurately determined by measurements to be taken after the completion of the road." Changes of route from the original route selected may be permitted under several elaborate regulations.

There are numerous physical requirements regarding construction, operation, and management of the road, of which a few of the most important are as follows: On narrow-gauge roads the weight of the rail must not be less than 25 pounds per yard; on standard-gauge roads it must be not less than 56 pounds per yard on grades of

110 feet to the mile or under, and must be at least 70 pounds per yard on steeper grades. Fences must be erected as soon as the land is appropriated for use. Cattle-guards must be provided. If the fences are not made or are not kept in good repair the corporation is liable for damages to domestic animals, but when they are kept in good repair the corporation is not considered liable for damages unless "negligently or willfully done." Barbed wire, however, is not permitted for fence construction. The railroad need not be fenced when it is not necessary to prevent horses, cattle, sheep, and hogs from going upon its track from the adjoining lands. Farm crossings must be maintained wherever necessary. Sign-boards of such shape and design as are approved by the Board of Railroad Commissioners must be placed at all grade crossings. The Supreme Court or the County Court may upon action require a railroad to station flagmen or even to erect, maintain, and operate crossing gates at any highway grade crossing. No station which has been established by the railroad shall be discontinued without the consent of the Board of Railroad Commissioners. All railroads crossing another railroad at grade must bring all trains to a full stop between 200 and 800 feet from the crossing, and then shall cross only when the way is clear and upon a signal from a watchman stationed at the crossing. If two railroads cannot agree as to expenses the matter will be decided by the Supreme Court. The full stop may be omitted with the approval of the Commissioners if interlocking switch and signal apparatus has been adopted. For ordinary steam railroads the permissible passenger fare is 3 c. per mile, with a right to a minimum single fare of not less than 5 c. The Legislature reserves the right to reduce fares, but cannot do so without the consent of the corporation, if it may be shown that the net profits would be less than 10% per annum on the capital actually expended.

CHAPTER III.

CAPITALIZATION.

12. Stock.—The total railway capital of the roads of the country, as reported to the Interstate Commerce Commission for the year ending June 30, 1904, aggregated $13,213,142,679. This capitalization was at the average rate of $64,265 per mile. The capitalization represented stock to the amount of $6,339,899,329, which is 47.98% of the total capitalization. This is slightly less than the percentage in previous years, although during the last eleven years this percentage has only varied from 47.44 to 50.87%. The average amount of stock per mile of line for that year was $30,836. This value has been singularly uniform for many years past in spite of the large increase in the mileage. This total issue of stock is divided into common and preferred stock, of which the preferred stock for the year given was $1,289,369,860, which was a little over 20% of the total. Preferred stock usually carries the right to a dividend at a fixed percentage, which dividend must be paid before any dividend can be declared on the common stock. Frequently, although not always, these dividends are cumulative, which means that if for a period of one or more years the railroad is unable to pay them, the defaulted dividends constitute a lien on the road which must be paid ultimately before dividends may be paid on the common stock. This stock therefore occupies an intermediate place between a bond and the common stock. It carries with it no authorization to foreclose and sell the road in order to secure a payment of either principal or interest, but, on the other hand, the interest or dividends, although definitely limited in amount, have a priority over the payment of any dividends on the common stock.

Although the capital stock per mile of line for the whole United States has been singularly uniform for a long period of years, which shows a uniformity in practice from year to year, there is a considerable variation, as might have been expected, in the capital stock per mile of line for railroads in the various groups. For example, the capital stock per mile of road in Group II, which includes New York, Pennsylvania, New Jersey, Delaware, and Maryland, is over $62,000 per mile. On the other hand, in Groups V and IX, which include the Gulf States, together with Kentucky and Tennessee, the capital stock is less than $20,000 per mile. This is only what might have been expected, considering the relative general wealth of the two sections. The percentage of the capital stock to the total capitalization, however, remains more nearly uniform. The lowest percentages are likewise in Groups V and IX. This indicates that although as a matter of fact the total capitalization per mile of road is less in these two groups than in any others, the issues of capital stock are a far less proportion of the total capitalization, and that the roads have been built chiefly on the capital obtained from the issue of bonds, probably subscribed more largely by non-residents. Although nearly the same disparity is shown in these two groups, and especially so for Group IX (Texas and Louisiana), regarding a low issue in bonds per mile of road, the percentage of the bond issue to the total capital is practically normal for these two groups.

13. **Funded debt.**—The total funded debt, which usually is about 50% of the total capitalization, consists of ordinary

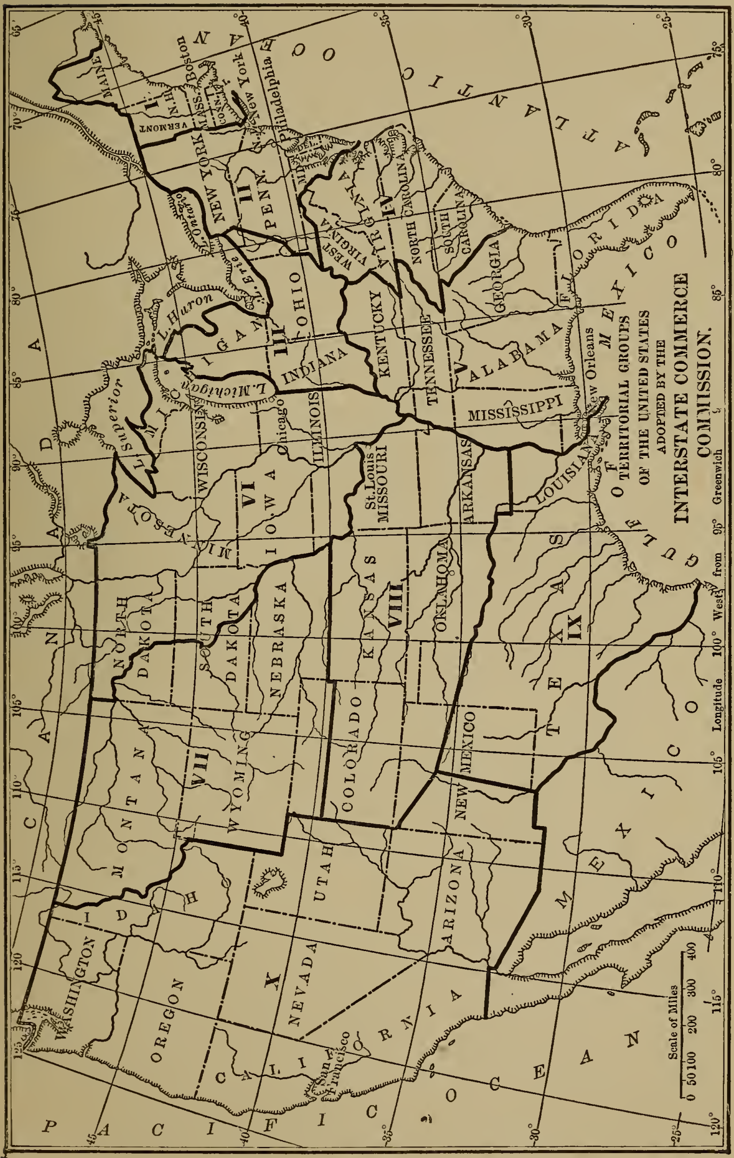

TERRITORIAL GROUPS
OF THE UNITED STATES
ADOPTED BY THE
INTERSTATE COMMERCE
COMMISSION.
I
II
III
IV
V
VI
VII
VIII
IX
X
MAINE
VERMONT
N.H.
MASS.
Boston
CONN.
R.I.
NEW YORK
New York
N.J.
Philadelphia
PENN.
DEL.
MD.
OHIO
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
FLORIDA
ALABAMA
MISSISSIPPI
TENNESSEE
KENTUCKY
INDIANA
ILLINOIS
Chicago
MICHIGAN
WISCONSIN
MINNESOTA
IOWA
MISSOURI
St. Louis
ARKANSAS
LOUISIANA
New Orleans
TEXAS
OKLAHOMA
KANSAS
NEBRASKA
SOUTH DAKOTA
NORTH DAKOTA
MONTANA
WYOMING
COLORADO
NEW MEXICO
ARIZONA
UTAH
NEVADA
IDAHO
WASHINGTON
OREGON
CALIFORNIA
San Francisco
L. Superior
L. Michigan
L. Huron
L. Erie
L. Ontario
CANADA
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
PACIFIC OCEAN
Longitude West from Greenwich
Scale of Miles
0 50 100 200 300 400
25°
30°
35°
40°
45°
65°
70°
75°
80°
85°
90°
95°
100°
105°
110°
115°
120°
125°

FIG. 4.

bonds, income bonds, equipment trust obligations, and miscellaneous obligations. An **income bond** is practically the same as preferred stock with cumulative dividends. They are issued only after ordinary bonds have been issued to as great an extent as is considered financially safe. The interest on these bonds is only payable after the interest on prior bonds has already been provided for.

Another type of bond which is frequently used during the reorganization of a bankrupt property is called a **convertible bond.** Such bonds carry a provision at some definite basis for their conversion into stock at the option of the holder.

Equipment trust bonds are really chattel mortgages which are issued to pay for unusual expenditures in new equipment. Since the property which constitutes the security of such a mortgage has a short life and will undoubtedly become practically worthless in a comparatively short term of years, such bonds contain provision for a sinking-fund by which the principal will be returned in annual installments and become entirely repaid within the estimated period of the physical life of the equipment.

All of these special forms of bonds constitute about 20% of the total bonded indebtedness. The great bulk of the bonded indebtedness consists of the ordinary form of bond with a definite rate of interest and with the provision that, if the interest is not promptly paid, the holders of the bonds may apply to a court for the appointment of a receiver, who will be authorized to administer the road if it is considered possible that a new management might succeed in rendering the property financially solvent, or else to arrange for the sale of the road under foreclosure. A foreclosure sale may be ordered not only for the failure of the road to pay the principal at maturity, but also for failure to pay the interest when it is due. The law varies somewhat regarding the rights of bondholders, but usually a very small proportion of them, even one-tenth, may institute foreclosure proceedings.

14. Dividends on stock.—A very brief investigation of the records of railroad stock will show that it is a very precarious form of investment. It is unfortunately true that but very few roads which are old enough to have a history have escaped a receivership, or at least a period in which no dividends were paid. Many stockholders have considered themselves lucky that their stock has not been altogether wiped out by a foreclosure sale. On the other hand, the returns on the stocks of some roads have been phenomenally large. Frequently a road will commence business by calling for a payment of 10% on its stock. As the demand for money increases and the credit of the enterprise diminishes by the issue of bonds until no more bonds will be taken up, the stockholders will be called on for larger payments on their stock-subscriptions. In many cases where the road is successful from the start and its prospects have been so great that a large proportion, if not all, of the cost of construction and initial operation have been obtained from the proceeds of the sale of bonds, the stockholders begin to earn dividends when they have only paid 10 or 20% of their stock. In the improbable case that the road is able to maintain such a record, a regular dividend of 6% on the par value would mean virtually a dividend of 60% (or 30%) on the amount *actually paid in.* But in spite of the very favorable showings made on some roads, the statistics show that a large proportion of railroad stock actually pays no dividends. During the depression following the panic year of 1893, there was a period of three years in which 70% of all the railroad stock of the country paid *no* dividends whatever. It is useless to minimize this statement by saying that much of railroad stock has been "watered." If a road pays no dividends, the original bona-fide payments for stock, as well as the "water" in the stock, get no return on the investment, and for that period of three years 70% of railroad stock paid no dividends. The 30% which succeeded in paying dividends only paid them at an average rate of about 5.6%. Since that time the situation has grown far better. The percentage of stock which pays no

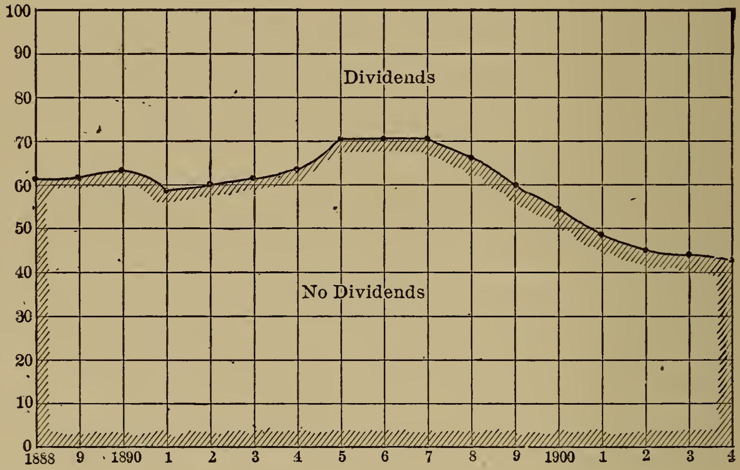


FIG. 5.—Percentage of stocks paying NO dividends.

dividends has been reduced to about 42%, and yet the last few years have been the most prosperous years known in railroad history. There is some mitigation of the above gloomy view when we consider that a large proportion, if not the total, of the stock of many small branch railroads is owned by the larger trunk lines, with which they connect, in their corporate capacity. The larger railroads utilize these smaller roads as feeders which add to the earnings of the main line. Even though the earnings directly assignable to the branch line are not sufficient to earn more than enough to pay the operating expenses and the interest on the bonds, the larger railroad company as owner is securing a return on its investment, in the indirect form of through-business furnished to its main line, which adds to the receipts of the main line far more than the added business costs. The fact that about 30% of all railroad stocks outstanding are owned by railways in their corporate capacity, and that some of it brings an indirect, if not direct, return, materially modifies the above statement regarding stocks which do not pay dividends.

If we analyze the situation with respect to different sections of the country, we find a very marked difference. Group VII, comprising the region between the Rocky Mountains and the Missouri River, has the best record regarding roads which failed to declare dividends, less than 8.5% having failed to do so. Over 40% of the stock in that group paid from 7 to 8 per cent. The largest amount of stock belongs to Group II; in this group a large percentage paid from 4 to 8 per cent. The Pacific States, Group X, are erratic, over 80% paying no dividends while 1¾% paid over 10%.

15. Interest on bonds.—The record of the payment of interest on bonds is of necessity far better than that of paying dividends on stock. Excluding equipment trust obligations from consideration, less than 4½% of the bonds defaulted their interest. Although the very large bulk of bonds pay from 3 to 6% interest, there is a considerable percentage which pays 7 or 8% and even a little over. Considering the railroads of the United States as one system (and thus eliminating the intercorporate payments made to a railroad which owns the bonds of another road), the net interest on the funded debt for 1903 and 1904 required a little over 14% of the gross earnings from operation. Even this figure is a considerable reduction from the corresponding figures for previous years, owing largely to the general policy of refunding railroad securities at a lower rate of interest. Although there is a very large variation in individual cases of the proportion of gross earnings which must be paid out for interest on the funded debt, it is remarkable that such a large percentage of all railroads expend nearly the same proportion of their gross earnings in this way. This uniformity seems to be regardless of the length of the road, except that, the larger the system, the greater the probability that the average figure will be approached. The largest variations from average figures occur with very small branch lines which are operated under special operating conditions and financial agreements.

16. **Taxes.**—The item of taxes is usually included under fixed charges. For the year ending June 30, 1904, the total amount paid in taxes by the railroads of the United States amounted to $61,658,373. Of this amount $1,324,808 was paid upon property owned by railroad corporations but not used in operation. If we deduct this from the total, we have, as the amount of this expense assigned to operation, $60,333,565. The *commercial valuation* of railroad property as given by the Bureau of the Census was $11,244,852,000. Upon this basis the average rate of taxation would amount to about $5.37 per thousand. The basis of the assessment of these taxes is somewhat variable, although over 70% is assessed on what is considered to be "the value of real and personal property." About 10% more of the tax was computed on the basis of the market value of the stocks and bonds or on a valuation of the road, which is based on the actual earnings, dividends, or other results of operation. In all States and Territories of the Union the first system is used, but in some States a second system is employed to supplement the first. In addition to the above systems, which may be called ad-valorem taxes, about 18% of the taxes collected were based on some special system of taxation, such as a tax on the gross or

net earnings, revenue, or dividends. Sometimes a tax is paid on the amount of traffic, or on some physical property of the road operated, or on some special privilege which has been granted. Sometimes there is a special taxation on stocks, bonds, loans, etc.

The amount of these taxes per mile of line of course depends chiefly upon the actual valuation of the road per mile, but it also depends upon the system of taxation in the various States and Territories. In the State of Massachusetts, where the valuation of the railroad per mile of line is very high, we would expect a high tax-rate per mile, but it is apparently far higher on the basis of actual valuation than in other States, since it amounts to $1426 per mile. Connecticut comes next with $1114 per mile. In the State of New Jersey, where the actual valuation of the railroads is nearly, if not quite, as high as in any other State, the amount of taxes per mile of line is $798, while in New York and Pennsylvania it is $581 and $482 respectively. In some of the Southern States, where the valuation of the railroads per mile of line is comparatively low, we find, as might be expected, a low tax-rate per mile, that in Florida being $150 and in Alabama $182. In Texas the rate is only $110, and in Indian Territory it amounts to only $19. The average for the whole United States is $301 per mile.

17. Small margin between profit and loss.—The gross revenue received by a railroad is applied first to the payment of operating expenses. As an average for the whole United States this amounts to approximately 65%. From the remainder must be paid the interest on the funded debt and current liabilities, and also the taxes. This will take about 20% more, but it is not even permitted to use all of the remainder for dividends, since a very large fund is needed for permanent improvements and for bolstering up weak branch lines which are not paying their expenses but which are operated because of their indirect or their future value. It will thus be seen that the dividends are only paid out of the last small percentage of the gross earnings. Since there is so much variation in the financial condition of railroads, from one which is unable to pay its operating expenses to another which is declaring dividends on watered stock, we may learn something by studying the statistics of all the railroads of the United States "considered as a system." This last phrase refers to the fact that, since such a considerable proportion of railway stock is held by railway companies in their corporate capacity, there is a very large percentage of payments made to and by railroad companies which are merely intercorporate payments. By deducting those payments, which would appear as receipts in the accounts of one road and as expenses in the accounts of another, we may prepare a statement such as would be made up if all the railroads of the country were actually combined into one system. Another condition which somewhat complicates the situation is due to the fact that railroads are also the owners of property which brings in an income totally independent of their work as common carriers. In 1904 this "clear income from investments" amounted to nearly $50,000,000, although it was only 2½% of the gross earnings, but such income has been ignored in the following statements. The table on page 35 gives the gross earnings of the railroads of the country considered as one system for the year ending June 30, 1904 (using even millions throughout).

The actual amount of surplus available for "adjustment and improvements" was nearly $50,000,000 in excess of the $94,000,000 surplus given in the table, on account of the added sources of income not included in "gross earnings from operation." It should be noted that in the above case the dividends were taken from the last 9.3% of the gross earnings.

Earnings from passenger service		$ 444,000,000
“ “ freight “		1,379,000,000
“ “ other sources		152,000,000
Gross earnings from operation		$1,975,000,000
Subtracting operating expenses		1,339,000,000
We have as net earnings		636,000,000
Out of these earnings were paid,		
Taxes	$ 62,000,000	
Interest on debt and on current liabilities	296,000,000	
and then dividends	184,000,000	542,000,000
leaving a surplus of		94,000,000

The dividends actually paid averaged less than 3% on the total capital stock. That which has been called surplus may almost be considered in the light of an expense, since it was not considered wise to increase the dividends beyond the amount actually paid. The average revenue per passenger per mile amounted to 2.006 c. The revenue per ton of freight per mile amounted to .780 c. If the passenger and freight receipts, as well as the rates on mail, express, etc., had been cut down 10% without any increase in business the amount available for dividends would have been entirely wiped out. Even cutting them down 5% under the same conditions would have cut the dividends in two. It may thus be readily seen that there is but a small margin between large dividends and no dividends, which will be produced by comparatively small differences in rates.

Of course the above should not be interpreted as meaning that a difference in the amount of business done will have the same effect on dividends. Although to a very considerable extent it is true that when times are hard and business is slack, so that the amount of traffic is reduced, the gross expenses of the railroads are cut down, they cannot be cut down in strict proportion to the reduction in traffic. It will be shown later on that the cost of running an extra train is by no means equal to the average cost of running all trains. To put it more concretely a railroad which is regularly running 20 trains per day each way can run one additional train per day each way for much less than $\frac{1}{20}$ of the average cost. Vice versa, the saving which is made by running one less train, because the traffic has been cut down, is less than $\frac{1}{20}$ of the average cost. If, therefore, a road is doing a certain gross amount of business which requires say 20 trains per day, a change of policy which increases or diminishes the amount of business done will increase or diminish the gross receipts in strict proportion to the change in the business, but the change in operating expenses will be far less. If the business is reduced say 10%, the gross receipts are reduced 10%, while the operating expenses are reduced probably not more than 4 or 5%, and the probable result is that all money which otherwise might be devoted to dividends has been entirely wiped out. On the other hand, an increase in business of 10% will not increase the operating expenses more than 4 or 5%, and therefore the amount for dividends may be nearly doubled. This fact may be made still clearer by a concrete example.

18. Variation in dividends due to small variations in business done.—Assume that by changes in the alinement the business obtained has been increased or diminished 10%. Assume that the operating expenses are 67% of the gross receipts. Assume that the amount required for taxes, for the interest on the bonds, and for such demands for permanent improvements, working capital, etc., as are considered essential before dividends can be paid, amount to 28%. We will have a balance left of 5% available for dividends. Assume a change of policy by which a 10% increase of business is obtained. As an approximate figure we may say that this additional business may be carried at a cost of 40% of the average cost of the traffic. We will also assume that the reduction of 10% in traffic reduces the expenses by a similar amount. The comparative effect may therefore be stated as follows:

		Business increased 10%.		Business decreased 10%.	
Operating exp. =	67	67[1+(10%×40%)	=69.68	67[1−(10%×40%)]	=64.32
Fixed charges, etc.......... =	28	....	=28.00	....	=28.00
	95		97.68		92.32
Total income....	100	Income.............	110.00	Income..............	90.00
Available for dividends........	5	Available for dividends.............	12.32	Deficit..............	2.32

The above comparison is useful chiefly to indicate a principle rather than as a computation of definite value. It indicates in one case that an increase in business which may be obtained perhaps by mere changes in management more than doubles the amount available for dividends. On the other hand, a decrease in business, which may be due solely to poor business management, not only wipes out a dividend but actually creates a deficit. The numerical accuracy of the calculations of course depends on the estimate that the additional business only increases the cost for handling by 40% of the average cost. While the cost of running additional trains will be more than 40% of the average cost per train-mile, the cost of running additional cars in a train, which is not actually limited by grade, will be far less than the proportional cost of an additional train. The additional cost is still less when the manager secures traffic to move in the direction in which the traffic is ordinarily least. It is still less when the freight is carried in cars which would otherwise return empty. In fact under the last condition the added receipts are almost pure profit and the additional cost is so insignificant that it might almost be neglected. Therefore the estimate of 40%, as used in the above calculation, might be considered as a conservative average. If the increase in business can only be obtained by an increased expenditure which will make a permanent addition to the fixed charges, the above method of calculation will show whether the improvement is justifiable. The accuracy of the calculations will then depend on the accuracy with which the future increase of business may be predicted, but if the increase in receipts is greater than the addition to the fixed charges, and particularly if it is very much greater, there can be but little question as to the value of the proposed improvement.

19. Practical limitations of capitalization.—Theoretically there is a definite limit to the proper capitalization of every railroad project. Even if it is possible to obtain from a credulous public more capital (in the form of bonds) than the project requires, the effect is to burden the road with unnecessary "fixed charges" for bond interest. If more stock is subscribed for and paid in than can profitably be used, the usual result is wasteful expenditure, and the inevitable result is a decrease in the rate of dividends. In either case the credit of the road is impaired by the reduction in net earnings. The result of the over-capitalization may be actually financial embarrassment.

The other extreme is far more common. The project may fail to attract the capital necessary to build the road properly and to operate it until its normal traffic income is being regularly obtained. If the obtainable capital is exhausted before the road is put in operation the loss to the projectors is very great and is sometimes nearly or quite total. In anticipation of such a predicament a road is sometimes opened for traffic, using rails or ties which are too light, using little or no ballast, uncompleted earthwork having narrow cuts and no ditches and very narrow embankments, and many other devices for reducing the cost of the road before traffic-trains are run. To some extent such measures are justifiable, but it should always be remembered that it is frequently very expensive "economy" and that the operating expenses are thereby increased—often to such an extent as to wipe out an easily obtainable profit. Although it is unfortunately true that the engineer of the road must make the best of the capital which is furnished him for the work, be it great or small, yet the recommendations of the engineer should largely control the efforts to secure capital. The engineer should be competent to recommend how much capital may profitably be spent to secure the greatest rate of net return on the capital invested.

20. Principles which should govern the amount of capital to be raised.—(1) The project should secure sufficient capital to insure the proper completion of the road and its operation until the normal traffic income is obtained. An estimate of this amount can readily be made and the projectors should not be satisfied with anything less. It might even be stated more strongly to say that the projectors are foolish to embark on the enterprise unless they have a reasonable certainty of raising this amount.

(2) The surveys may develop the fact that some additional expenditure may permit an improvement on the line as originally laid out. An illustration of this (elaborated in Chapter XV) is the reduction of the rate of the ruling grade, which is shown to have a definite financial value. The criterion in such a case is this: If the improvement is unquestionably justifiable, on the basis of a *reasonable* capitalization of the annual saving in operating expenses, then the improvement should be made, *unless* there is danger that the total available capital is limited and that the whole enterprise may become imperiled by

an expenditure which is not absolutely essential even though desirable.

(3) In considering such a case as the above, the possibility of merely deferring the extra expenditure without ultimately abandoning work already done must be considered. In some cases the plan as actually constructed becomes practically a finality, which cannot be changed except at prohibitive loss. Under such conditions the best plan (from the operating standpoint) must be insisted on.

(4) On the other hand, no change or "improvement" should be adopted, unless it can be demonstrated that the change itself will be financially justifiable. It is not sufficient that its cost will not wreck the enterprise.

(5) The engineer can usually count on the fact that unless the money market is abnormally disturbed by panic conditions any enterprise which is really meritorious can command sufficient capital to float it, if it is properly exploited. Even an improvement to the original plan can command capital if it has sufficient merit, although this may be more difficult than to raise the original sum asked for.

CHAPTER IV.

THE VALUATION OF RAILWAY PROPERTY.

21. Objects.—There are several objects for which a valuation is placed on railway property. The method of making the valuation as well as the value arrived at is apt to depend very largely on the purpose for which it is made. An estimate may be made for the purpose of taxation. Another and very different estimate may be made by the agents of individuals or a corporation who are contemplating buying the property. Legislatures may wish to obtain a valuation which may be used as a basis for some form of railroad legislation. The fact that some railroad properties have become very valuable and have returned very large profits to their promoters has caused a general belief throughout the country that railroad earnings are far higher than a fair return on their valuation will justify. This has resulted in the demand that railway-rates should be reduced so that the net earnings will be more nearly in proportion to the true valuation of the road. Some of the methods of appraising railroad property will be here discussed.

22. Nominal valuation.—The nominal valuation of a railroad property is the sum of the par values of its stocks and bonds. On the basis that a bond is a mere evidence of indebtedness and that it represents money which has been used to create the property, the bondholder may be considered as one of the owners of the road and that his rights and control of the property are merely somewhat different from those of a stockholder. If the capital stock is not fully paid, then of course the true valuation must be considered as the sum of the paid-in capital together with the bonds and other liabilities. Of course such figures are very approximate and are discussed chiefly on account of their simplicity. When the road is first constructed, such figures ought to be a fair representation of the value of the physical property, provided expenditures have been cautiously and efficiently made. Such a valuation does not assign any value to the franchise or the charter of the road. A railroad property is very different from any other form of landed property. A tract of land, averaging about four rods in width and an indefinite number of miles in length, is diverted from its original use as farmland or other purposes and devoted to a particular use. A very large amount of money is spent in grading, in the construction of tunnels and the building of bridges, and the construction of the road-bed and track. Except for the comparatively insignificant value of the rails, which may be torn up and sold as second-hand rails, or the value of steel bridges, which may be removed and erected elsewhere or sold for scrap, all the money which is spent for the construction of the road is absolutely sunk beyond hope of reclamation. It can only be used for one purpose, and the value of the property as an investment is represented by its earning capacity when used for its one sole purpose of being a common carrier. Thereafter its value is really represented, not by the amount of money which has been sunk in the enterprise, but by the capitalized value of the road as an organization for earning money in one particular way—that of a "common carrier." If the road is well located for obtaining business, which is virtually the same as saying that it has a valuable franchise, then it will probably earn dividends on a comparatively small expenditure of capital. On the other hand, if there is but little business to be done, its earnings will be small, no matter how much the road may have cost. We may thus see that the amount which has been spent on the construction of the road does not *necessarily* bear any relation to the real value of the railroad property. Practically the two values will ordinarily approach equality. If the amount of money which has been spent is far higher than is justified by its earning capacity, it simply indicates that the expenditure has been foolishly made. If, on the other hand, it is far less, then it means that the promoters have seized an unusual golden opportunity. It would seem unnecessary to point out any further fallacies in the method of valuation from the amount of money spent in construction, if it were not for the fact that so many people still cling to some such method. Such a method sometimes gives values which are far too great, while in other cases they are far too small. To quote from one writer on the subject: "The commercial value has nothing to do with its cost. If John Smith buys a hotel for $1,000,000 and, although a good hotel man, cannot make more than $50,000 a year out of it, and wants to sell, the commercial value is probably not over $500,000." A hotel man might go into a wilderness, select a site for a hotel on land which costs him practically nothing, build a summer resort at a comparatively small expenditure, and in a few years create a custom and give his hotel a name and reputation which would make his hotel property exceedingly valuable and worth many times its original cost. Under such conditions, the market value of that hotel would have little or no relation to its actual cost.

23. **Cost-of-replacing-property method.**—There is a large class of people who think that a road should be valued

according to the cost of replacing the property at the present time, i.e., buying the right-of-way, constructing the road-bed and track, and providing its equipment. There are several causes which will operate to make such a valuation very unfair. Such a valuation takes no account whatsoever of the earning capacity of the road. A railroad may be so well located that its annual earnings are very large, so large that the public values its stocks and bonds, as quoted in the stock-market, at a very high figure, and yet the cost of duplicating that road in every particular at present-day prices might be very much less than the market price of its securities. As another reason, it is almost invariably found that any business enterprise, whether it is a factory or a railroad, which has been in existence for a series of years long enough for a considerable part of its construction to have been renewed by methods which were not in vogue when the structure was originally built, has had a total amount of money spent on it which is very far in excess of the amount which would replace it at the present day. It would certainly be unfair to say that, because a railroad-cut, for example, which was originally dug out by hand labor at a high price per cubic yard could now be taken out with steam-shovel methods at one-half the cost, therefore those who had paid the high prices for the original work should now have the railroad earnings scaled down until they give merely a return on the cheapened method of construction. This method is usually advocated by those who wish to make it a basis for radical legislation which shall reduce railroad charges until they merely pay the cost of operation plus a comparatively insignificant return on what it would cost under present methods to reconstruct the road. Such methods seem to lose sight entirely of the fact that the element of risk in railroad construction is very great, and that, as given in a previous chapter, a very large proportion of railroad stock pays absolutely no dividends. Therefore it is but just that the permissible earnings of railroads should be made high enough to compensate for the great risk which is run by capitalists who build railroads.

24. Valuation of physical properties and franchise.—In Michigan and Wisconsin the railroads of the State have all been valued by a corps of engineers, appointed by the State, who adopted a systematized method of making an actual valuation of the property as it exists. Of course the method was largely an estimate of the cost of reproduction, allowance being made, however, in those elements such as rails, etc., which are subject to wear and depreciation, for the "present value." The various elements of cost of a road were classified, and those elements which were subject to depreciation were examined particularly, while making the appraisal, to determine their present value. For the railroads of Michigan, the total cost of reproduction of construction and equipment was given as $202,716,262, while the present value was given as only $166,398,156, or 81.4% of the value when new. Switch-ties and cross-ties were allowed a present value of only 53.9% of the cost of reproduction. Telegraphs and telephones were allowed only 52%, while, on the other hand, right-of-way, real estate, and grading were allowed their full value, 100%. Although this work was undertaken by the State with the idea of furnishing a basis for a more uniform system of taxation, "it very soon became necessary to publish an order excluding all thought of taxation in connection with the results to be obtained." "The commissioners required of us only the cost of reproduction and the present value of this road, reserving to themselves any adjustments of these values that might be thought necessary to secure uniformity of taxation."

There was added to the "present value" of these properties the sum of $35,814,043 as the value of the "non-physical" properties. The non-physical property is supposed to include among other things the following:

"1. It includes the franchise

"(*a*) To be a corporation.

"(*b*) To use public property and employ public authority for corporate ends.

"2. It includes the possession of traffic not exposed to competition, as, for example, local traffic.

"3. It includes the possession of traffic held by established connections, although exposed to competition, as, for example, through-traffic that is secured because the line in question is a link in a through-route.

"4. It includes the benefit of economies made possible by increased density of traffic.

"5. It includes a value on account of the organization and vitality of the industries served by the corporation, as well as the organization and vitality of the industry which renders the service; this value consequently is, in part, of the nature of an unearned increment to the corporation." (From report of Professor Henry C. Adams.)

The value of the non-physical properties was obtained by deducting from the gross earnings from operation the operating expenses, exclusive of taxes, which gives the net income from operation. Adding to this the net income from corporate investments would give the total available corporate income. From this is deducted an annuity, based at 4% of the mean value of the physical elements, which then gives the remainder available for other purposes. From this was deducted further the taxes on the physical elements at 1% of their mean value, also the rentals on property not covered by the appraisal, also the interest on current liabilities, and also the cost of permanent improvements which were charged to income.

Subtracting these deductions from the remainder obtained above, we have a surplus (or deficit) which is capitalized at 7%. This gives such a value of the non-physical elements that it yields a net income of 6% after the payment of taxes of 1%. It is a very curious coincidence that when the value of the non-physical properties of the railroads of Michigan, as it was actually computed according to the above method, was added to the "present value," the sum total agreed with the cost of reproduction to within a quarter of 1%. It is probable, however, that this should be considered as a coincidence rather than as an illustration of a general law.

25. Stock-market valuation. — A far more accurate method of valuation is to determine the average market value of the stocks and bonds of the road for a period of time which is long enough to cover the speculative fluctuations of the stock-market. There is one very strong reason for considering this as a true valuation. The market price for railroad securities is determined as a compromise between two opposing classes of financiers, one of which is interested in raising the price as high as possible, the other in making it as low as possible. Such men are experts in valuation. They make it their life-long business. The compromise value which is offered and accepted between these two classes of experts may therefore be considered as the true valuation of the property, provided we can succeed in eliminating from the price the effect of fluctuations due to speculative excitement. The combined value of these securities (stocks and bonds) represents the value placed upon the earning capacity of the railroad.

26. Valuation by capitalizing the net earnings.—This method requires two steps: the determination of, first, the income to be capitalized, second, the rate of capitalization. The determination of the income to be capitalized is not very difficult, although it requires some modification from the "net earnings" as reported by the railroad companies, with which it should be identical. The difficulty arises from the variation in the methods of railroad companies, in keeping their accounts. The net earnings represent the difference between the gross earnings and the amount properly assignable to operating expenses. For the purpose of this investigation such taxes as are paid are allowed as operating expenses so that the remainder represents the total which can be applied as a return in whatever form to the capital which has been invested. The chief difficulty lies in the variation among railroad accountants in charging expenditures for permanent improvements. One company may purchase additional rolling-stock and charge the entire cost to operating expenses. Others will charge the entire sum to the capital account. If the new equipment is partially to replace old and antiquated equipment, some will adopt the plan of charging the value of the replaced cars or locomotives to operating expenses and charge the remainder to the capital account. The last method is undoubtedly the correct method to adopt, since any permanent addition to the equipment of the road should be charged to capital account and not to operating expenses. Assuming that we have the rate of capitalization, if we divide the net income of the road by this rate of capitalization it will then give a valuation of the property which represents its actual financial worth. The determination of the proper rate of capitalization is very difficult and must be determined according to some fixed rule rather than by assigning an arbitrary value. A minute difference in the rate of capitalization will produce a very large difference in the resulting value of the road. The method adopted by the United States Department of Commerce and Labor may be very briefly indicated as follows:

The market quotations on the securities of each railroad were studied for a period of over six months previous to a given date; even this period was extended in the case of abnormal fluctuations. The details of each issue of debt, the amount outstanding, the rate of interest, the dates of the payment of interest, and the date of maturity were determined. The effect of accrued interest and expected dividends on the prices of securities was allowed for. Since the record of sales only includes a very small proportion of the railroad securities in existence, even the bid and ask prices, which resulted in no sales, were considered. Under usual conditions the bid price represents the lower limit of the market value of the security. The ask price represents the upper limit and the difference represents the zone within which bargaining takes place. On the general principle of adopting a lower valuation in case of doubt, the bid price was used as the basis upon which to value the securities considered. The actual return to a bondholder on a bond which matures at a given time is a very complicated mathematical function of the annual interest rate and of the length of time still remaining for the bond to run. Sets of tables are published which give the average rate per cent in annual return on bonds purchased at various prices above or below par. The rate of annual return on bonds of the road, on the basis of their market price and the date of their maturity, was then figured for each issue of bonds. Multiplying this rate by the actual market value of the bonds gives the virtual annual return to the investor. Dividing the sum total of these annual returns by the sum total of the market values then gives the average rate of income on the bonds which were actually sold or on which bidding prices had been determined. The valuation of the funded debt, which was not quoted on the stock-market, was estimated by giving it a valuation corresponding with other similar securities. Multiplying these values by the same rate per cent per annum will give the annual return on the unlisted securities. We can then add up the values for the actual (or probable) market value of all the funded debt of the road and also the computed annual return to the investor and, by dividing the return by the total market value, we obtain the average annual return in rate per cent per annum. The market price of the stocks, together with their actual dividends, are similarly obtained, but there must be added to the market price of these stocks an estimate which will represent the undivided profits which have not been returned to the stockholders in the form of dividends. "No well-managed corporation divides at any one time among its stockholders the precise amount of its gain since its last preceding dividend. Such a proceeding is not only impractical but also impossible, for the reason that it is impossible to tell precisely what the corporation gains have been during such a period. . . . The physical property has, to at least some extent, changed its identity during the period; the credits and obligations of the corporation have probably changed; the general aspects of its business opportunities have almost certainly changed; and all of these together have correspondingly modified the value of its physical property." Some of these improvements can be definitely allowed for. For example, the average annual expenditures for permanent improvements which have been made during a period of say five years should be added as though it were a dividend, since it might be considered as a dividend paid to the stockholder and immediately reinvested by him in the capital stock of the road. Similarly, variations in the profit-and-loss account, as indicated by the general balance-sheet, can be allowed for by considering the average annual *change* in the profit-and-loss item for a period of years. Even if there had been a loss each year a steady reduction in that loss may be considered as an average *increase* in the profit account.

Another item to be added is due to the fact that the sum of the actual annual payments of interest and guaranteed dividends may amount to more than the computed annual return based on the market price of the bonds. This annual excess must be added in order to compute the actual annual return to the investors of the road. In fact the only object of computing the annual return, based on the market price and the time of maturity of the bonds, was that a proper average rate could be obtained on which to compute the return on the unquoted securities. There is still one other item which may need to be added: if the returns on the common stock are based on the present rate of dividends, but the dividends have varied during a period of say five years, which is the period adopted for the annual averages of betterment, etc., we must consider that a reduction in some rate of declared dividend means that so much money has been added to the profit-and-loss account of the road, and therefore the average amount of this difference, spread out during a period of say five years, represents the average addition (or deduction) which must be made to or from the average income of the road. Taking the summation of these average returns and dividing it by the summation of the market (and computed) prices of all forms of the securities of the road, we determine the actual average annual return in rate per cent on those securities.

Dividing the net earnings of the road by this computed rate of capitalization then gives the valuation of the entire property.

Legal Control.

27. The subject of the legal control of railroad corporations by the federal, State, and municipal governments is so very broad that several volumes would be required to adequately discuss even the present condition of such regulation. A large part of the subject (the making of rates) is usually considered to be entirely outside of the province of the engineer, since the engineer is never called on to make rates or to revise them. But there are many cases where a knowledge of the method actually employed by railroad managers in making and revising rates, and the control which has already been exercised by the State and federal governments over rate-making, will give the engineer a much clearer idea of the influence which rate-making has on many of the problems which daily come before him. It may be more accurate to say that he should understand how *little* rate-making is affected by such variations in engineering design as he is able to control. In the next few pages an attempt will be made to very briefly state a few of the fundamental principles regarding the methods of rate-making and the control of rates which is exercised by the State and federal governments.

28. Basis of freight-rates.—The usual method of setting a price on a manufactured commodity is to determine from actual experience what is the cost of manufacturing the commodity and to add to such cost an amount which will pay a reasonable return on the capital invested, and also pay a reasonable return to the manufacturers to compensate them for their time, skill, and knowledge of the business. If the manufactured article is secured by patents and is in great demand, the profit added to the cost of the manufacturing will be correspondingly large, and yet even this is considered right since the owners of a valuable invention are entitled to a corresponding profit on the invention. Ever since legal control of railroad-rates has been suggested there has been an effort to establish a basis of cost of transportation, so that by adding a reasonable amount, which will pay for the use of the capital, a proper charge may be determined, and that the railroad shall be enjoined from attempting to collect any greater charge for such transportation. A consideration of some of the facts already stated, together with demonstrations made in subsequent chapters, will show that the cost of transportation is a very variable quantity. It will be shown that, even though we determine from statistics of the whole country that the average cost of transporting one ton per mile is about .5 c., we cannot therefore say that the cost of transporting one ton for one mile on any particular railroad and under all conditions will be .5 c. or even approximately so. Even if we were to establish from the statistics of any one given road that the average annual cost of transporting freight on that road amounted to a certain figure, it would be neither fair nor equitable to say that all traffic should be charged according to this figure, that no traffic should be taken at any less figure, nor that any charge could be made at any greater figure. To a very considerable extent it is true that railroad expenses are independent of the amount of business done. The fixed charges must be paid regardless of the amount of business, if the road is kept solvent. The cost of maintaining the road-bed and track is very largely independent of the amount of traffic. Whether there are twenty trains per day each way or only one, the amount of track-work which is necessary to keep the road up to a given standard will not be proportional to the number of trains. Although the fuel bill will vary more nearly in accordance with the amount of traffic, it will be by no means strictly in accordance with it. The practical result of all this is that railroad profits are subjected to "the law of increasing returns." The first half of the business which is done costs a large proportion of the total; the final ten per cent is almost clear profit. A railroad is very often compelled to accept some of its business at a rate which is much lower than the average rate or it cannot get the business at all. It can handle the additional business at a net *additional* cost which will be less than the amount received for it and hence can make a profit on such business. Under such conditions the business is profitable. If it is attempted to increase the charge for this low-grade business to the average rate for all business it will not get it at all. If it is attempted to reduce the charges on its local non-competitive business to the lower average rate actually received the road cannot pay its expenses and must go bankrupt. These facts may be illustrated by a very simple concrete example, in which the figures make no pretense of accuracy and are given merely for the purpose of illustrating a principle. Suppose that a road is handling 80,000 tons of non-competitive freight per year, for which it receives $1 per ton; suppose that it has an opportunity of handling 80,000 additional tons of competitive freight at the rate of 60 cents per ton; its gross receipts are therefore $128,000. The competition is such that it *must* accept the competitive freight on the basis of 60 cents or refuse it altogether. It is therefore handling 160,000 tons of freight at an average rate of 80 cents per ton. Assume that it could handle its non-competitive business alone at a total expenditure, for operating expenses and fixed charges, of 90% of the amount received or $72,000 for the 80,000 tons. Assume that the extra business, whose cost is confined to comparatively small additions to the cost of maintenance of way, maintenance of rolling stock, and the expenses of conducting transportation, costs but 50 cents per ton. The additional business is therefore handled at a cost of $40,000, and the entire traffic at a total expenditure of $112,000, which leaves a net profit of $16,000 on the business. Although the competitive business is handled at a far less rate than the non-competitive business the net profit on that part of the business alone is $8000, which is as great as the profit on the non-competitive business. If, in response to attempts to enforce uniform rates, the charges were cut down to the uniform basis of $128,000 on 160,000 tons of freight or an average price of 80 cents per ton, we would find that the additional competitive freight could not be obtained at all. The road would then be compelled to attempt to pay its operating expenses by handling the 80,000 tons of freight at 80 cents, which would give a revenue of only $64,000 when the actual expenses, including fixed charges, are supposed to cost $72,000. Such a condition of affairs could only lead to bankruptcy. The condition of competition is one that a road is forced to meet.

29. **Direct competition.**—A road that is already bankrupt is usually the one which most recklessly breaks established rates and starts a rate war. Such a road will enter the most reckless competition in order to obtain business under any conditions. A rate which will pay operating expenses, even though it necessitates a default of the interest on the bonds and, of course, pays no dividends, is doing better than to remain idle, since, if it pays the operating expenses, it is at least maintaining its road-bed and track in some sort of condition. Therefore such a road will try to obtain business at *any* rate which will actually pay the operating expenses. The solvent road which is so situated that it must meet the competition of the road which is recklessly cutting rates has forced upon it the alternative of accepting business at

much less than its usual rates or refusing it altogether. If the general manager can estimate that such business can be handled at a rate which will more than cover the *additional* operating expenses, he is justified in accepting the business, especially since it will actually prove a source of profit to the road. It is claimed that those who ship their freight on the non-competitive high rates are helping to pay the freight of others. This is not true, since the others will not pay anything to the road except at the reduced rate. As a matter of fact, it might even be said that the low-rate shipper helps to pay the freight of the high-rate shipper, since the profits of the road are increased by the payments made by the low-rate competitive shipper, thus enabling the road to reduce the rates of the high-rate non-competitive shipper. We are thus led to the conclusion that freight-rates are not, and cannot be, based on any rational estimate of the cost of service. The railroads really charge "what traffic will bear," and this charge is determined very largely by causes over which the railroads have little or no control. This will be discussed later.

30. Indirect competition.—It has frequently been stated in this book that the prosperity of a railroad company is very intimately connected with that of the community which it serves. A large part of the business of a railroad is freight business. The freight business of a railroad depends on the business prosperity of its customers. Commercial competition requires that a manufacturer shall not only manufacture his goods as cheaply as his competitors, but that he shall also be able to deliver the goods at the very door of his customers as cheaply as another manufacturer. Since a very considerable item in this total cost is the cost of transportation, it becomes a matter of business for the railroad to assist the manufacturer by making the freight-rate, if possible, at such a figure that it will permit the manufacturer to meet the competition of others. If the manufacturer cannot do this, he cannot do business at all, and the railroad company loses his business altogether. This course of reasoning is the justification of the discriminations which have been practiced by railroad companies in favor of certain shippers. These shippers could not do business profitably, except at certain freight-rates which were below the normal. The railroads could handle such business as extra business at a profit, and could make more money on such an arrangement than by not handling the business at all. Of course there are reasons which make such discriminations unjust as well as illegal, especially when these methods have been used to build up the wealth of great monopolies. A treatise of this sort is not the place to discuss discriminations, but the above statements have been made to show why discriminations may be profitable to the railroad company. The indirect competition furnished by other railroads, who are trying to build up their own prosperity by building up the prosperity of the shippers along their lines, is one of the most potent causes to reduce freight-rates, even to a shipper who has absolutely no choice except to ship his goods on the one road which passes his place of business. The railroad company is therefore virtually compelled to reduce its freight-rates to a point where they will pay the operating expenses and leave as much margin as possible on the capital investment. It will thus be seen that a profit which is made out of the low-grade competitive business will actually enable the railroad management to reduce the freight-rate on the so-called non-competitive business, if it is found necessary to do so in order that the local shipper may meet the competition of another shipper on a railroad perhaps 200 miles away.

31. Justification of special commodity rates.—In the following chapter the methods of estimating the volume of traffic of a new railroad enterprise will be discussed. The discussion there chiefly concerns the methods of estimating the *volume* of the business. Although the freight-rates obtainable on such business will usually bear some relation to the similar rates charged by other railroads, the rates will not necessarily be identical. In fact the estimator must have sufficient knowledge of commercial business to know the market prices of commodities in the markets reached by his road, and to know, for example, the market price of hay in a certain city and the rate that may be charged for transporting hay which will leave to the farmer a sufficient amount per ton to encourage him to raise and haul hay to the railroad for shipment. If the freight-rate charge is excessive, so that there is but little object for the farmer to raise hay, the railroad will lose such business altogether. It would be preferable for it to charge a lower rate per ton than is charged for other merchandise, rather than to discourage and lose the business altogether.

32. Low rates on low-grade freight. — The preceding paragraph furnishes the basis of the justification of an apparent discrimination between different kinds of freight. From the operating standpoint it costs just as much to haul a ton of coal as to haul a ton of furniture or expensive machinery, and yet the universal custom is to handle coal, broken stone, and similar products which have comparatively little value per ton, at a much cheaper rate than articles of higher value. This is partly done on the general principle that the traffic will bear a higher value. In the case of coal, even the low freight-rate is a large proportion of the total value of the coal. In the case of machinery or dry-goods, the freight charge is comparatively insignificant. The shipment of low-grade, bulky freights would be considerably discouraged by a marked increase in the freight-rates. The much higher rates which are charged on high-grade freight is such a small proportion of their total value that their use is not appreciably limited by the freight-charges.

As a conclusion of this very brief discussion on freight-rates, it may be said that the fundamental principle of freight-rates is that the charge is made in accordance with what traffic will bear—interpreting this phrase to mean that the prosperity of the railroad is bound up with the prosperity of the community served, and that the railroad will have more business and obtain a greater profit by encouraging the business and permitting the prosperity of the community. And it will best accomplish this by reducing its freight-rates to the point which will so encourage business that the return to the railroad company will be a maximum.

Federal Control.

33. Origin.—The authority for the control of railroads by the federal government is based not only on the principle of the governmental control of "common carriers," but also on the provision of the Constitution that Congress has the power to regulate the commerce between States. It is quite probable that this provision was inserted in the Constitution chiefly, if not entirely, with the idea of preventing the collection of import and export duties on merchandise passing between the States. Railroads were non-existent at that time, were hardly even dreamed of, and certainly the framers of the Constitution had not the slightest conception of the present railroad situation. Nevertheless on this very slender basis has been built up the elaborate series of decisions which have been rendered by the U. S. Supreme Court in the many recent railroad cases. Of course it required no authority greater than that of common law for Congress to deal with railroads as common carriers which are subject to its jurisdiction. Inasmuch as the consolidation of railroads during recent years has made every important railroad system enter two or more States, there is but little railroad traffic in the country which is not subject to federal control. Federal control has been exercised partly as a result of the very extensive grants of public land which have been donated to railroad companies to encourage the building of important roads, such as the Union Pacific Railroad. The authority of Congress to control railroads even to the making of reasonable freight-rates has been thoroughly affirmed by decisions of the U. S. Supreme Court. The control exercised by Congress over railroads has been principally centered on the regulation of freight-rates. In addition to this, acts have been passed to regulate the use of safety appliances, such as automatic couplers, air-brakes, etc.

34. Necessity for control.—A private shipper has but little hope of satisfaction if he considers that a given freight-rate on a shipment of goods is unreasonable. If the goods have already been shipped, the charge must be paid before the goods can be recovered at the other end. Theoretically the law provides that he can complain to the Interstate Commerce Commission that the charge is unreasonable. Although the Interstate Commerce Commission is empowered to order a railroad to reduce its charge to "reasonable rates," it does not have the power to state what a reasonable rate shall be. Regardless of the Interstate Commerce Law, the shipper can bring an action against a railroad company in an ordinary court upon the complaint that a rate is unreasonable, and if he can establish the point, the railroad must refund whatever has been proven to be the excess. But when the cost of such proceedings is taken into consideration, there is no object for the shipper to bring such an action either before the courts or the Interstate Commerce Commission. Even the powers of the Interstate Commerce Commission have been so limited by the decisions of the Supreme Court that the shipper has very little recourse under the present conditions of the law. The railroad company is protected by the constitutional provision that rates cannot be reduced to such an extent as to make them "confiscatory." But since it would be practically impossible to demonstrate that any individual rate would be confiscatory, the provision is of little practical use to the railroads. The reasonableness of a rate is very difficult to prove, except by a comparison with similar rates under similar conditions. The chief provision of the Interstate Commerce Act is what is commonly called the "long-and-short-haul clause," which forbids a railroad from charging more for a short haul than for a long haul in the same direction and under similar conditions, the short haul being included within the long haul. The words "under similar conditions" have been the loophole which has practically nullified the long-and-short-haul clause. The railroads have successfully maintained the existence of *a difference in operating conditions* which justifies them in accepting some shipments of competitive freight at less rates than other shipments of non-competitive freight on which the haul was actually somewhat less.

35. **Pooling.**—Unrestricted competition on competitive freight has proved very disastrous to railroad companies, especially when they have endeavored to prevent their business from slipping away from them by reducing their rates in order to meet competition below the point where it even paid the actual additional cost of operation. To avoid such cutthroat competition many competing rail-

roads formed what were called pools, under which they agreed to maintain rates and to insure to each of the competing roads their proportion of the freight business. The passenger pools were sometimes arranged in the same way. The proportions assigned to each road were determined by the actual business of that road during the previous year. The pools were of two kinds, money pools and traffic pools. On the basis of the money pools, each road was allowed an agreed share of the total receipts on the business done by *all* the roads, almost regardless of the work which it actually did. Some slight adjustment was made by allowing roads which had handled more than their rated share of business a small extra amount which would partially compensate them for the extra work which they actually did. But the compensation was purposely made so small that it would be no object for the railroad to attempt to get more than its share of business. The traffic pools were managed so that the actual traffic of the roads would be kept at the prearranged ratios, this being accomplished by diverting traffic to roads which showed a tendency to fail to get their due share. Since shippers usually object to the diversion of their freight shipments, certain large shippers, who were called "eveners," consented to allow their shipments to be diverted to any route so as to even up the traffic to the different roads. Of course they were allowed concessions in the freight-rate on account of this arrangement. But as pooling was popularly supposed to be detrimental to competition, it was declared illegal by federal legislation and has been discontinued.

36. Traffic associations.—It has been attempted to maintain competitive freight-rates between railroads by means of traffic associations. The traffic associations which have been formed have adopted uniform systems of classification together with uniform systems of freight-rate charges which would prevent rate-cutting. The many attempts in this direction have been rendered ineffectual, because the railroads themselves would not abide by the schedules. One freight agent would suspect (justly or otherwise) that another freight agent was cutting rates and he would proceed to meet the cut. A rate war would soon be in progress, which would probably disrupt the association. Even traffic associations were declared illegal, on the ground that they were "in restraint of trade." Traffic associations are still in existence, but their powers have been legally curtailed. Any attempt in their by-laws to discipline any road for an infraction of their rules is declared illegal. All agreements regarding rates are merely "gentlemen's agreements" and this gives no guarantee of immunity from a rate war.

37. **Consolidation.** — Pooling and traffic associations having been declared illegal, the only method left to prevent competing roads from ruining each other financially by means of rate wars was to cut off all incentive for competition by consolidation. Even this has been somewhat prevented by legal provisions against the consolidation of parallel or competing lines. But such prohibitions have not prevented the elimination of competition by combinations of groups of capitalists who so control the roads on the principle of "community of interests" that there is practically no such thing as an active competition which has an effect in cutting down rates. Consolidation has already progressed to such an extent that the great railroads of the country are now combined into a very few groups and are owned or controlled by a comparatively small number of men. Since the reduction in rates through active competition is now practically hopeless, the only means of preventing the railroad from being the sole judge of how much it shall demand from a helpless shipper appears to lie in the

power of Congress to directly specify what a traffic-rate shall be. This power appears to be only limited by the common-law rule that "it must be reasonable," which, of course, includes the constitutional provision that "it must not be confiscatory."

State Control.

38. Scope and limitations.—The scope of State control is somewhat the same as that of federal control, but it has different limitations. It must be subject to federal control and cannot apply to any traffic except that in the State. Like the federal control its authority is based chiefly on the principle of a governmental control of common carriers. The control actually exercised by the States applies chiefly to police regulations as to their physical condition. Railroad charters are usually granted by State legislatures. These have already been discussed in Chapter II. The control by the States of such matters as grade crossings, etc., has also been referred to. Comparatively few of the States have interfered with the rates which shall be charged by a railroad, except as it has been done in the charters of the railroad. Even the limitations imposed by the charters are frequently so much higher than the rates which the railroad company themselves see fit to charge, that it cannot be said to have any influence on rate-making. Space is too limited to discuss the so-called "granger legislation," which was the all-important political controversy in the Northwestern States several years ago. The prevalent opinion that freight-rates were extortionately high produced very drastic legislation, cutting down the charges which the railroads were permitted to make. The legislation went too far, and the result was financial embarrassment and even bankruptcy for many of the roads. Much of this legislation has since been repealed. Some of the State Railroad Commissions, notably that of Texas, have been active in recent years in regulating the charges made by the railroads. It remains to be seen whether this action will prove beneficial alike to the railroads and to the communities.

Other elements of State control have already been discussed in Chapter II.

CHAPTER V.

ESTIMATION OF VOLUME OF TRAFFIC.

39. Primary considerations.—The economic considerations underlying the building of railroads are now fundamentally different from those existing fifty or sixty years ago. In 1840 the number of miles of railroad in the United States was 2818. In sixty-four years that mileage was multiplied by more than 75. At that time the number of miles of line per 10,000 square miles (100 miles square) of territory was only 9.5. Now it is 720. At that time nearly the whole country was virgin territory, and it was not a question of the ultimate success of a road, provided it was constructed with a decent regard for sound engineering principles, but a mere question of time before the country would develop sufficiently to support the road.

In a broad way we may now say that the railroads of the country are built. The great trunk lines have developed practically all of the available east and west routes, at least between the Atlantic and the Middle West, and all of the necessary lines from north to south. More tracks will doubtless be built, but they will be the expansion of one- and two-track lines into four, or even six-track roads, or the construction of short stretches of expensive reconstruction to obtain low-grade lines. If irrigation succeeds in transforming parts of the great West from deserts into fertile farms, there will probably be an enormous increase in railroad building in the West, but even this will be under different circumstances and conditions from those under which our railroads were built during the period from 1860 to 1890. If we examine a railroad map of the United States, it will not be easy to find a spot in the New England States (except Maine), in the Middle Atlantic States, or in the States around the Great Lakes, which is 20 miles from any railroad. If we consider that the whole country was gridironed with railroads running north and south and east and west at a distance apart of 30 miles, only one point in each square would be as far as 15 miles from any road. Such squares would have 60 miles of road for 900 square miles of territory or 6.67 miles per 100 square miles of territory. The average for the whole United States (7.20) is even now greater than this. Florida and Texas are the only States east of the 100th meridian in which the number is less than 6.67.

The practical meaning of the above is that the railroad building of the future, at least in the eastern part of the United States, will probably be confined to the construction of comparatively short cross-country lines whose chief purpose is to give additional facilities to sections of territory which already have railroad lines within ten to twenty miles. This again means that a railroad will not usually be able to monopolize all traffic in the territory through which it passes and for as many miles back from the railroad as railroad influence may be considered to extend, but that it must directly compete with other roads for its traffic. Of course it will have a virtual monopoly on sources of traffic which are so near to its line that no other road could obtain such traffic except at a prohibitive sacrifice, but it will mean that for some distance out of large cities, which are entered by several railroads from approximately the same direction, the traffic will be largely competitive. It will frequently be found that a very large proportion of the traffic of a railroad is competitive traffic and that the strictly non-competitive traffic, the local traffic which it picks up from its own immediate territory, is comparatively unimportant. On this account we must largely modify the methods of estimation which would have been proper many years ago and also estimates based on the history of roads which have been long established, since in general those roads began under traffic considerations which are different from those of a new road of the present day.

40. **Methods of estimating volume of traffic.**—We may first begin with the most rapid, easy, and approximate methods which have their value, because their rapidity and simplicity renders them easy to apply and they at least form a valuable check on other and more elaborate methods. In Table III are shown the gross "earnings from operation" for the whole United States for each year, from 1894 to 1904 inclusive, and in the next column the actual or estimated population. Dividing one by the other we have the average earnings per capita for the whole United States. It is interesting to note from this

TABLE III.—GROSS AND PER-CAPITA RAILROAD EARNINGS—WHOLE UNITED STATES.

Year.	Gross earnings from operation (millions).	Population (thousands).	Earnings per capita.
1894	$1,073	67,800	$15.83
1895	1,075	69,100	15.55
1896	1,150	70,400	16.33
1897	1,122	71,700	15.65
1898	1,247	73,000	17.08
1899	1,314	74,300	17.95
1900	1,487	75,600	19.67
1901	1,589	76,900	20.66
1902	1,726	78,200	22.07
1903	1,901	79,500	23.91
1904	1,975	80,800	24.44

the comparatively low value of these receipts in 1894, which immediately followed the panic year of 1893, and how, by an almost uniform rise, the receipts have increased about 60%. These values, after all, are but average values, and are the average of the whole ten sections into which the area of the United States is divided by the Interstate Commerce Commission. By reference to the map of the United States shown in Fig. 4, it will be seen that the whole territory of the United States is divided into groups. These groups are found to vary considerably in the character of their population, its density, the number of miles of railroad per hundred square miles of territory, and in the amount contributed per capita. In Table IV are shown the gross earnings for the year 1900 as divided among the different groups.

TABLE IV.—STATISTICS OF MILEAGE AND GROSS EARNINGS IN DIFFERENT SECTIONS OF THE UNITED STATES (1900).

	Mileage.	Number of miles of line per hundred square miles of territory.	Number of miles of line per 10,000 inhabitants.	Gross earnings per mile operated.	Gross earnings per capita.
Group I....	7,622	12.30	13.63	$12,392	$17.31
II.....	21,481	19.88	12.91	16,514	21.55
III.....	23,403	18.66	24.38	9,273	23.14
IV.....	11,894	8.53	20.71	5,250	10.39
V.....	22,672	7.57	21.05	5,323	10.62
VI.....	43,448	11.73	34.31	6,727	23.74
VII.....	10,930	2.64	66.49	5,233	35.05
VIII.....	23,775	6.51	37.80	5,363	20.30
IX.....	12,233	3.74	30.78	4,664	13.97
X.....	15,889	2.09	51.13	6,349	30.49
United States..	193,346	6.51	25.44	$ 7,722	$19.67

The figures in the last column are not based on data which are so accurate that the figures may be considered to be precise, but the errors involved are certainly small and the figures are amply accurate for our purpose. The figures are seen to vary considerably from the average receipts per head of population for the whole United States. As a general statement it is true that the estimated earnings for a road to be constructed in the territory of any one of these ten sections would be given more accurately by the average figure for that section than by the figure given for the whole United States. Such a figure has its value as a first trial and preliminary estimate of the probable traffic of a road.

41. Estimate of earnings per mile of road.—It is sometimes attempted to quickly estimate the probable earnings per mile of road by a comparison of the *earnings per mile* of existing roads which are similarly situated. The gross earnings per train-mile for every railroad in the United States are given in the statistics of the Interstate Commerce Commission. We will consider first the gross earnings per mile of road and per train-mile for the ten greatest railroad systems of the country and will also consider similar figures for ten small railroads which are chosen at random, except that their mileage is invariably less than 100 miles and also that they are all independent railroads, and therefore it need not be considered that their gross earnings are dependent upon their relationship to a larger trunk system. These figures are given in Table V.

An inspection of these figures will show that the gross receipts per mile of road are exceedingly variable, even for roads in the same section of the country and of approximately the same mileage. On the one hand, it will be seen that the earnings per mile of road of the five small roads in Group II are all very much smaller than the average per mile of road for that group. The earnings per mile of road evidently bear a close relation to the frequency of the train service, and this of course is exceedingly variable. There is hardly a possibility of uniformity until we deter-

Table V.—Gross Earnings per Mile of Road and per Train-mile for Great and Small Roads (1904).

No. in Report.		Mileage.	Gross annual receipts.		Gross earnings per train-mile.
			Per mile of road.	Per mile of road for that group.	
	Whole United States	220,112	$9,306		$1.94
52	Canadian Pacific	8,382	$5,540		$1.92
1412	C. B. & Q.	8,326	7,640		2.04
1407	Chicago & Northwestern	7,412	7,190		1.71
939	Southern Railway	7,197	6,270		1.49
1433	C. R. I. & P.	6,761	5,580		1.64
1534	Northern Pacific	5,619	8,300		2.66
1383	A. T. & S. F.	5,031	8,330		2.17
1471	Great Northern	4,489	8,080		2.94
1242	Illinois Central	4,374	10,710		1.58
975	Atlantic Coast Line	4,229	4,860		1.67
	Average of ten		$ 7,250		$1.98
78	Montpelier & Wells River	44	$ 4,095	13,994	$1 45
134	Somerset Railway Co.	42	2,960	13,994	1.35
349	Hunt. & Broadtop Mt	66	11,560	20,187	1.82
374	Lehigh & New England	96	1,990		1.14
396	Ligonier Valley	11	6,570		2.06
486	Newburgh, Dutch. & Conn.	59	2,910		1.08
660	Susquehanna & N. Y.	55	3,625		1.74
769	Detroit & Charlevoix	51	1,770	11,863	2.11
1239	Harriman & Northeast'n	20	4,510	6,679	2.73
1835	Galv., Hous. & Henderson	50	7,560	5,443	3.29
	Average of ten		$4,755		$1.88

mine the average revenue per train-mile, which is also given in Table V. In this case, however, there is a uniformity which is really remarkable in spite of the variations which are seen. It may be noted that the average revenue per train-mile for the large roads is much more nearly uniform and that it closely approximates to the average value for the whole United States as might have been expected. The revenue per mile from the smaller roads, while it covers a far larger range than in the case of the larger systems, is nevertheless a figure with some limitations. It seldom drops below $1, and the cases are rare where it rises above $3. But even such a figure is of but little value until the proper number of train-miles per year may be determined, and this after all brings us back to the point where we started, viz., the determination of the amount of traffic from which we may obtain an idea as to the number of trains. It is perfectly true, as elaborated later, that on roads of very small traffic the number of trains will not be strictly proportional to the number of passengers carried nor to the gross number of the tons of freight. Nevertheless, if the number of trains is increased in order to encourage traffic, the revenue per train-mile will be reduced, although it is sometimes a wise proceeding to do so.

42. Estimate of tributary population.—Having decided on some estimate for the receipts per head of tributary population, even if it is only for a preliminary and rough estimate, the next step is to determine the number of the tributary population. A large map with a scale of say one mile to the inch is of considerable assistance in determining this. On this map, which may be one of the easily obtainable railroad maps or a set of maps such as are published by the U. S. Geological Survey, we may see the location of all existing railroads. The proposed road will probably pass to some extent through territory considered exclusively its own. If it passes through a valley, so that it is separated on either side by high hills from the valleys occupied by other railroad lines which are perhaps ten miles away, it may reasonably claim all of the population within the valley through which it passes. The population of this area may be determined with sufficient accuracy from census records or other sources. Where the road passes through towns which are already served by one or more lines, it is not right to consider that the entire population of that town will contribute per annum the average per-capita quota. In fact it would be more nearly true to say that the per-capita quota multiplied by the population of the town will be distributed among all the roads concerned in the relative proportion of their importance. Or, in other words, if we divide the population of the town into parts which are proportional to the relative importance of the roads, we may consider that the income from that town will equal that proportion of the total population multiplied by the average per-capita figure. By thus computing the tributary population for each section of the road we may multiply the sum total by the assumed per-capita figure and obtain a rough estimate of the gross receipts.

43. Estimate by comparison with other roads. — Still another method of estimating the gross revenue from operation is to obtain the figures of the gross revenue of an existing road which is operating under conditions which are similar to those of the proposed line. This might be done by saying that since the existing line has gross receipts of so much per mile, and since the proposed line will have very similar advantages, the receipts per mile of road should be substantially the same. Perhaps a still better method than the above would be to estimate the tributary population of the existing road by the method indicated in the last section. An estimate should then be made of the population which would be tributary to the proposed line. Dividing the gross receipts of the existing line by its tributary population would give a fairly reliable estimate of per-capita receipts from such a community. Multiplying this figure by the tributary population of the proposed line would then give a fairly close estimate of its probable revenue. Probably the greatest danger underlying the above method comes from the inaccuracy of the assumption that the existing road and the proposed road will operate under similar conditions or that their tributary populations will have equal revenue-producing capacities. An experienced man may however use this method by making a suitable allowance when he considers that the proposed road will be more valuable or less valuable than the line with which it is compared. Even though this method is confessedly inaccurate and subject to error, it should generally be utilized, because it is nearly always possible to obtain sufficient data for the purpose with but little trouble, and the results obtained are a valuable check on the results which will be computed by the other methods.

44. Actual estimation of the sources of revenue.—Practically the only accurate method of making any such computations is to study the entire territory which will be served by the road and estimate in detail the amount of business which will be obtained from every manufacturing plant, mine, lumber-camp, and even every farm. Through country districts and through towns which are not already served by a railroad such an estimate is not very difficult. Generally the errors will be on the safe side, unless rendered valueless by a gross exaggeration of the expected increase in business. A factory which can do business without railroad facilities will frequently multiply its business many times when it is connected with the outside world by a railroad which passes its doors. It is usually safe to estimate a freight-charge not only on the entire present output of the factory, but to even consider that the factory will grow and furnish a much larger amount of business. An experienced estimator will soon estimate the probable yield of the farms which are within five miles of the road and what would be the probable market for the produce when it became possible to ship it by rail. In estimating what farms should be thus included the distance from the farm (perhaps in an opposite direction) to another railroad and also the nature of the roads and the hills should be taken into consideration. It is usually possible to predict with certainty that a farmer who had previously hauled his entire output over a steep hill for a distance of seven or eight miles to an existing road will transfer his entire business to the new road because the new road will be only three miles away and the grade is downhill. It may even be justifiable to consider that the farmer will produce more of certain kinds of crops, since the accessibility to the markets produced by the proposed road will encourage him and will enable him to make profits which were unobtainable before. Of course the estimator must have sufficient knowledge of mercantile values to know what are the probable markets, not only for farm-produce, lumber, and minerals, but also for manufactured products. The estimator will consider each proposed station on the road in turn and will estimate (considering first the freight business) that the farms within reach of that station will annually bring to that station so many tons or car-loads of various kinds of farm-produce which will probably be shipped to a certain market, or at least will be shipped from that station to one or the other of the termini of the road where they will connect with other lines. Multiplying that tonnage of produce by a suitable freight-rate for the distance will determine the receipts for those items. Each lumber tract, each mine and each factory should be considered in the same way. Unless there is some place along the line where certain products are consumed the traffic of this kind will usually run from the local station to one or the other of the termini. Of course there will be a small amount of local freight traffic between stations along the line, but this is usually a comparatively small proportion of the business done.

45. Estimation of passenger traffic. — Statistics show that the proportion of the passenger revenue to the total earnings is roughly constant, and yet it varies considerably in the different groups. This is best shown in Table VI.

TABLE VI.—PUBLIC SERVICE OF RAILWAYS, BY GROUPS (1900).

Group.		Proportion of total earnings, per cent.	Earnings per capita.	Passenger service.			Freight service.		
				Number of passengers carried one mile per mile of line.	Average number of passengers in train.	Average journey per passenger.	Number of tons of freight carried one mile per mile of line.	Average number of tons in train.	Average haul per ton.
I	Pass.	38.05	$ 6.59	259,503	60	18.46	572,796	178	82.76
	Frt.	53.47	9.26						
	Other	8.48	———						
II	Pass.	22.04	4.75	202,902	47	20.74	1,900,578	355	110.91
	Frt.	71.59	15.43						
	Other	6.37	———						
III	Pass.	20.22	4.68	94,154	39	35.18	1,221,286	329	117.32
	Frt.	72.22	16.74						
	Other	7.56	———						
IV	Pass.	20.99	2.18	46,543	32	38.59	620,143	296	203.80
	Frt.	71.72	7.46						
	Other	7.29	———						
V	Pass.	19.98	2.12	45,263	28	38.63	467,703	203	116.06
	Frt.	71.94	7.65						
	Other	8.08	———						
VI	Pass.	19.53	4.64	62,115	35	32.48	586,524	244	143.64
	Frt.	71.73	17.04						
	Other	8.74	———						
VII	Pass.	18.82	6.60	41,323	39	91.48	360,370	217	204.73
	Frt.	73.47	25.77						
	Other	8.21	———						
VIII	Pass.	18.59	3.77	42,794	31	46.36	385,193	186	170.75
	Frt.	72.66	14.76						
	Other	8.75	———						
IX	Pass.	18.29	2.55	37,266	32	52.97	363,278	198	173.21
	Frt.	74.69	10.44						
	Other	7.02	———						
X	Pass.	25.90	7.90	77,873	60	37.45	394,355	261	237.07
	Frt.	67.14	20.49						
	Other	6.96	———						
Whole U. S.	Pass.	21.77	4.28	83,295	41	27.80	735,366	271	128.53
	Frt.	70.56	13.88						
	Other	7.67	———						

By examining this table in connection with the map of the United States (Fig. 4) showing the different groups, much may be learned regarding the character of these groups, and the effect of that character on railroad earnings. For example, in Group I (the New England States), although the gross earnings per capita are smaller than the average, the passenger earnings per capita are large, and this is in spite of the fact that the average journey per passenger (18.46 miles) is less than in any other group. Freight earnings, however, have a lower percentage in this group than in any other. The average haul per ton and the number of tons in a train is less than any other group. On the other hand, Group VII (see Table VI), which includes the States of Montana, Wyoming, Nebraska, and portions of Colorado and the Dakotas, pays a larger amount per capita to the railroads than any group in the United States. This is largely due to its enormous freight business, which furnishes nearly three-fourths of the total earnings with a gross amount equal to $25.77 per capita. Even the passenger earnings are $6.60 per capita, which is more than 50% of excess of the average for the United States. The average journey per passenger was 91.48 miles, which is far in excess of that in any other group and between three and four times the average for the whole United States. The railroads in Groups IV and V have the lowest earnings per capita. The percentages of passenger and freight business are in each case about equal to the average for the country, but the earnings per capita are very small. Another rare and abnormal case is found in Group X, the Pacific Coast States. This section of the country has "magnificent distances." The average haul of each ton of freight is 237 miles, which is nearly twice the average, and the average freight and passenger earnings per capita are in each case about 50% in excess of the average. Such differences in the characteristics of the various sections of the country must be kept in mind when making any estimate of the expected traffic on a proposed line.

Conditions which Affect Volume of Traffic.

46. **Proximity to sources of traffic.**—It has elsewhere been emphasized that the most important general requirement of the locating engineer is that he shall so locate the road that it shall obtain the maximum business. Every other requirement should be subordinate to this. This is unquestionably the best policy, since in the long run the road which best serves the community will obtain the greatest business.

The construction of a railroad through a large city, or even into the heart of a large city which may be a terminus of the road, is a very expensive matter. The engineer and the board of directors are confronted with the almost irresistible temptation to avoid at least a part of such expense by placing the station (or the terminus) farther and farther from the heart of the city. Generally the loss of business resulting from such supposed economy is not directly apparent to the non-expert, especially if there is no competition, and even the expert will have difficulty in accurately estimating the loss. But we may learn from past experience, and there are fortunately several conspicuous examples of the relative volume of business obtained by competing roads whose traffic facilities are very different. In the early '80's, the entire line of the New York Central and the Lake Shore & Michigan Southern between New York and Chicago was practically paralleled by a competing line. The older roads were built during the early history of railroad building, went through the heart of every city and village, and into the very centers of their termini. At the time the competing roads were constructed, access to the business centers of these cities and villages was far more difficult and expensive. At Painesville, Ohio, for example, the Lake Shore road passes within a block or two of the chief business streets. The depot of the "New York, Chicago, and St. Louis R.R." was about three-fourths of a mile out of town and could be reached only by an unpaved country road. In other places the relative traffic facilities were about as unequal. In New York City the N. Y. Central penetrates the city to its terminus at 42d St. The West Shore terminal at Weehawken is not only much farther in an air-line distance from the business center of the city, but is separated by a river only to be crossed by a ferry, and even then the traveler is landed on the river-front and a long tedious street-car ride is an essential for nearly all. Under such circumstances, the cutthroat competition which ensued between the two roads could only have one possible ending. Excluding from consideration the strictly local non-competitive traffic, the "West Shore" and the "Nickel Plate" could not hope to obtain any of the through competitive passenger business except by a ruinous cut in rates. Of course the older roads were much better able financially to endure the rate war and, although it affected their dividends, the effect on the new roads was bankruptcy, receiverships, and sales under foreclosure. The unequal struggle for freight business was about as hopeless for the new roads. In New York City, where such a large proportion of the freight-terminal transfers are made by shifting freight-cars on floats, the West Shore had a fighting chance, but in the smaller cities and villages, the merchant or manufacturer frequently had the choice of hauling freight a block or two over paved streets to the old railroad, or hauling it half a mile or a mile over an unpaved country road to the new railroad. Of course the new road was compelled to make some concession, either by reduced freight-rates or by free teaming, to equalize the difference. The net result was the same—financial ruin. Possibly it may be said that the promoters of the West Shore and Nickel Plate never expected their roads to compete on equal terms—that the projects were really blackmailing schemes to compel the older roads to buy them out. Even if this is so, the history of the competition of these roads is an instructive example of the effect of unequal facilities on the traffic obtainable from a community.

Another very instructive example of the effect of a difference in facilities affecting the traffic is given in the competition of the P. R.R. and the B. & O. R.R. for passenger business between Philadelphia and Baltimore. The P. R.R., by an expenditure aggregating millions, has made its Philadelphia terminal under the very shadow of the City Hall. The B. & O. R.R., although it paid out very large sums for its entrance into the city, made its terminal at Twenty-fourth and Chestnut streets. Whatever may be the reason that the terminal was not placed nearer the City Hall, the fact remains that it is over a mile away, and a street-car ride is almost an essential for the great bulk of its passenger traffic. The terminal as constructed, although not comparable with Broad St. Station (P. R.R.), is far larger than the business of the road requires. The waiting-room has been fittingly described as "lonesome." The student should note that a handicap on facilities not only affects business but literally kills certain classes of business. In spite of the enormous expenditure made by the B. & O. R.R., its facilities do not equal those of the P. R.R., and the result is ruinous for competitive passenger business.

47. Estimation of effect of location of station at a distance from the business center.—So many factors enter into such a question that no exact solution is possible. The chief factor is the proportion of competitive business.

On business where there is direct competition the road with less facilities must either give up the competition for such business or offer some compensating advantage which will probably consume nearly all, if not quite all, of the profits on such business. On other business which is non-competitive the disadvantage will not be so great, although even here it must not be ignored. The late A. M. Wellington attempted to answer this question by the statement that the location of a station one mile from the heart of the town will affect the business from that town anywhere from 10 to 40%, depending on the circumstances, and that 25% might be considered an average figure. For each succeeding mile he deducted 25% of the remainder. Of course such an estimate is at its best a very loose approximation.

48. Extent of monopoly in railroad business.—A very common mistake among railroad promoters is to assume that a railroad passing through any section of country will be able to collect "all the traffic there is," disregarding for the present any competition from another road. This idea is probably responsible for many of the blunders which have caused a road to be located in a way that hampered traffic, when the only object gained was a very insignificant economy in the first cost of the road. The student should not forget that railroad traffic varies in its character from the absolutely necessary traffic, for which any reasonable or even unreasonable sum would be paid, to the extreme of unnecessary traffic, such as traveling for pleasure, which is absolutely dependent upon the facilities offered. Even freight business depends on the total cost of transporting goods from their location in a factory or mine to the very door or warehouse of the consumer. The laws of competition require that the manufacturer must be able to manufacture his goods and deliver them to the door of the consumer in a distant city as cheaply as his rival can deliver goods of the same quality at the same destination. Anything which facilitates such transportation, not only affects the factory or mine, but it may make all the difference between profit and loss on the whole transaction. Therefore the prosperity, not only of the railroad, but also of the mining and manufacturing interests, depends on the promotion of railroad facilities. In a town where there is no competition the railroad may have a monopoly so far as any other railroad is concerned, but, unless facilities are created to handle goods with economy and to transport passengers conveniently, the amount of traffic developed will be very greatly reduced. The strictly necessary traffic which a railroad might claim as a monopoly is so very small that very few railroads could pay their operating expenses from it. The dividends of a road are declared out of the last small percentage of the revenue, and such revenue comes from the unnecessary traffic, which must be coaxed and encouraged, and which is so very easily affected by the lack of facilities and conveniences.

Perhaps the best general statement which may be made regarding the question of locating a station near the business center of the town is that it depends on the limit of capital which may properly be put into the enterprise, provided the project as a whole is not financially wrecked by the expenditure. There is hardly a limit of expenditure which would not prove a paying investment *in course of time* in order to locate a road within a block of the business center of a town. It should never be considered as a project which may be deferred, since the price of land invariably increases and usually multiplies many times after the road has been constructed, so that a future construction into the heart of a town or city becomes almost prohibitive unless at enormous expense.

PART II.

OPERATING ELEMENTS OF THE PROBLEM.

CHAPTER VI.

OPERATING EXPENSES.

49. Classification of operating expenses.—The following classification of operating expenses follows the system adopted by the United States Interstate Commerce Commission for many years, not only because the method of division is probably as good as could be devised for the purpose, but also because it will render the following discussion uniform with their system and therefore permit the utilization of the values given by them. The expenses are first divided into four groups, which are as far as possible independent of each other. The average value for a period of ten years (from June 30, 1894, to June 30, 1904) is as given in the table on page 84.

It should be remembered that the figures are exclusively *percentages.* The growth of railroad business has been so uniform that the *gross* amount spent for each item, and even subitem, is usually larger with each succeeding year, even though the percentage of that item to the gross expense is smaller.

50. Average operating expenses per train-mile. — The reports published by the Interstate Commerce Commission give the operating expenses per train-mile for nearly all

	Average value.
1. Maintenance of way and structures. This value ranges between a minimum of 19.519% in 1904 to 22.272% in 1901.	21.034%
2. Maintenance of equipment. The percentage of this item has varied from 15.761 in 1895 to 19.967 in 1904. With two slight exceptions this item has regularly increased each year, not only in gross amount, but also in the percentage of this expense to the total.	18.024%
3. Conducting transportation. The percentage of this item has varied from 59.460 in 1895 to 54.671 in 1902. Although the gross amount has largely increased, the *percentage* of this item has been decreasing with almost uniform regularity.	56.636%
4. General expenses. The percentages of this item are nearly uniform, varying from 3.789% in 1903 to 4.756% in 1897.	4.306%
	100.000%

of the railroads of the country. In fact the omissions are almost exclusively those of the very insignificant railroads on which the bookkeeping and tabulating of expenses is not kept up with sufficient accuracy to furnish such figures. The very surprising feature of these figures is that the operating expenses per train-mile are so nearly uniform. Although there are numerous instances where the average cost of running a train per mile over any one road has a large variation from the average figure for the whole United States, it will be found that the cases of very large variation are comparatively rare, and it will also be found that when the variation is very large there is usually some abnormal operating condition which accounts for the unusual value. The average cost of running a train one mile for the whole United States, as given for each year, is given in Table VII. The variation is shown graphically in Fig. 6.

The enforced economies following the panic of 1893 brought down expenses to the low point given for 1895.

TABLE VII.—AVERAGE COST PER TRAIN-MILE FOR WHOLE UNITED STATES—1890–1904.

Year.	Average cost per train-mile, cents.	Year.	Average cost per train-mile, cents.
1890......	96.006	1898......	95.635
1891......	95.707	1899......	98.390
1892......	96.580	1900......	107.288
1893......	97.272	1901......	112.292
1894......	93.478	1902......	117.960
1895......	91.829	1903......	126.604
1896......	93.838	1904......	131.375
1897......	92.918		

From this point the rise has been almost steady, until the annual cost is nearly 50% higher than in 1895. This has been partly due to an increase in wages and salaries, and partly due to the increased cost of fuel and supplies; but

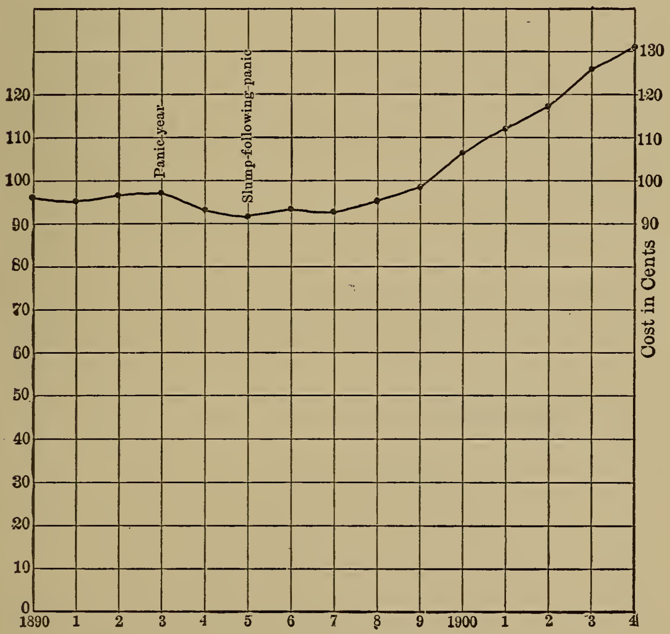


FIG. 6.—Average cost per train-mile in cents.

in spite of this increase, the uniformity between roads of various amounts of traffic is still remarkable. In Table VIII are given values showing the operating expenses per train-mile for ten of the largest railroad systems in the country, and also for ten small roads whose mileage is less than 100 miles.

TABLE VIII.—OPERATING EXPENSES PER TRAIN-MILE ON LARGE AND SMALL ROADS (1904).

No. in Report.		Mileage.	Operating expenses per train-mile.	Ratio, expenses to earnings.
	Whole United States.	220,112	1.314	67.79
52	Canadian Pacific.	8,382	1.320	68.72
1412	C. B. & Q.	8,326	1.313	64.35
1407	Chicago & Northwestern.	7,412	1.136	66.61
939	Southern Railway.	7,197	1.048	70.30
1433	C. R. I. & P.	6,761	1.199	72.90
1534	Northern Pacific.	5,619	1.392	52.26
1383	A. T. & S. F.	5,031	1.305	60.05
1471	Great Northern.	4,489	1.464	49.72
1242	Illinois Central.	4,374	1.107	70.02
975	Atlantic Coast Line.	4,229	0.984	58.95
	Average of ten.	. . . . . .	1.227	63.39
78	Montpelier & Wells River.	44	1.169	80.73
134	Somerset Railway Co.	42	0.802	59.37
349	Huntingdon & Broadtop Mountain. .	66	0.950	52.10
374	Lehigh & New England.	96	0.793	69.80
396	Ligonier Valley.	11	1.427	69.33
486	Newburgh, Dutchess & Connecticut .	59	0.922	85.09
660	Susquehanna & New York.	55	1.368	78.47
769	Detroit & Charlevoix.	51	1.424	67.52
1238	Harriman & Northeastern.	20	2.162	79.26
1835	Galveston, Houston & Henderson. . .	50	1.556	47.27
	Average of ten.	. . . . . .	1.257	68.89

In Table VIII the ten large railroad systems represent the ten largest railroads of the country. The ten small roads were chosen almost at random, except that the operating mileage is invariably less than 100 miles and the roads are all classified as "independent roads," so that their operating expenses need not be considered as being unduly affected in one way or the other by their relations to any corporation controlling them. It may be noted that, although the average cost per train-mile is more uniform in the case of the larger railroad systems, as might have been expected, and that the variations from the average are much greater in the case of the small roads, the variations doubtless being due to special and local conditions, nevertheless the small roads show operating expenses per train-mile which are sometimes above and sometimes below the average values for the whole country or for the larger systems, but their average does not greatly differ from that of the average of the large systems. Without attempting to elaborate the explanation of the causes of this uniformity, it may be seen in general that although the larger railroads have very large expenses, which on the smaller roads are very small (if they exist at all), yet, since the divisor (the number of trains) on the large road is so very large, the quotient, which is the average cost per mile, tends to become uniform. It should also be noted that the ratio of earnings to expenses on the ten large systems and on the ten small roads remains at a fairly constant figure.

51. Itemized classification of operating expenses.—The reports made to the U. S. Interstate Commerce Commission are given according to such a standardized system that the entire operating expenses of the railroads of the country (with the exception of about one-sixth of one per cent) may be classified. Although such detailed figures are not published for each railroad, the averages for all the railroads are published each year. The comparison of the percentages for each year are very instructive, especially when it is possible to trace the cause of the fluctuations in those percentages. The classification

TABLE IX.—SUMMARY SHOWING CLASSIFICATION OF OPERATING EX-
OF EACH CLASS TO TOTAL FOR THE

No.	Item.	Amount, 1904.	Per cent.		
			1904	1903	1902
	Maintenance of Way and Structures.				
1	Repairs of roadway......	$138,300,607	10.348	11.093	11.331
2	Renewals of rails........	17,345,483	1.298	1.386	1.521
3	Renewals of ties..........	33,668,585	2.519	2.487	2.838
4	Repairs and renewals of bridges and culverts...	29,778,004	2.228	2.461	2.593
5	Repairs and renewals of fences, road crossings, signs, and cattle-guards.	5,839,385	.437	.527	.625
6	Repairs and renewals of buildings and fixtures..	28,697,616	2.147	2.590	2.562
7	Repairs and renewals of docks and wharves....	2,789,094	.209	.235	.220
8	Repairs and renewals of telegraph............	2,385,300	.179	.165	.173
9	Stationery and printing...	392,801	.029	.032	.031
10	Other expenses..........	1,669,816	.125	.209	.361
	Total.............	$260,866,691	19.519	21.185	22.255
	Maintenance of Equipment.				
11	Superintendence.........	$ 7,572,965	.567	.559	.601
12	Repairs and renewals of locomotives...........	105,633,752	7.904	7.408	7.246
13	Repairs and renewals of passenger-cars.........	26,078,106	1.951	2.044	2.157
14	Repairs and renewals of freight-cars...........	103,932,132	7.777	7.442	7.432
15	Repairs and renewals of work-cars.............	3,081,998	.231	.242	.245
16	Repairs and renewals of marine equipment.....	2,065,442	.154	.177	.215
17	Repairs and renewals of shop machinery and tools.................	9,411,076	.704	.696	.643
18	Stationery and printing...	566,948	.042	.046	.044
19	Other expenses..........	8,515,198	.637	.519	.544
	Total.............	$266,857,617	19.967	19.133	19.127
	Conducting Transportation.				
20	Superintendence.........	$ 23,533,951	1.761	1.742	1.711
21	Engine- and roundhouse-men................	125,440,824	9.386	9.562	9.401
22	Fuel for locomotives.....	158,948,886	11.893	11.675	10.776
23	Water-supply for locomotives................	8,894,551	.666	.614	623

PENSES FOR THE YEAR ENDING JUNE 30, 1904, AND PROPORTION
YEARS ENDING JUNE 30, 1904, TO 1895.

Per cent.							Average ten years.	No.
1901	1900	1899	1898	1897	1896	1895		
10.924	10.995	10.720	10.643	10.644	10.738	10.235	10.767	1
1.676	1.138	1.322	1.391	1.546	1.444	1.499	1.422	2
3.140	3.036	2.901	3.232	3.357	3.028	2.948	2.948	3
2.730	2.703	2.374	2.512	2.472	2.265	2.268	2.461	4
.598	.616	.487	.537	.509	.561	.520	.542	5
2.417	2.466	2.181	1.957	1.745	1.794	1.648	2.151	6
.283	.308	.254	.245	.231	.270	.235	.249	7
.158	.153	.142	.137	.126	.135	.134	.150	8
.029	.030	.026	.025	.024	.027	.033	.029	9
.317	.352	.446	.349	.318	.372	.304	.315	10
22.272	21.797	20.853	21.028	20.972	20.634	19.824	21.034	
.599	.597	.632	.656	.667	.666	.629	.617	11
6.695	6.730	6.208	5.887	5.663	5.978	5.660	6.538	12
2.277	2.263	2.164	2.188	2.265	2.216	2.211	2.174	13
7.436	7.687	7.038	7.210	6.376	7.193	6.008	7.160	14
.233	.252	.210	.159	.140	.145	.121	.198	15
.234	.251	.247	.242	.215	.173	.167	.207	16
.605	.604	.512	.486	.478	.520	.455	.570	17
.043	.043	.040	.038	.039	.040	.041	.042	18
.507	.502	.544	.493	.509	.460	.469	.518	19
18.629	18.929	17.595	17.359	16.352	17.391	15.761	18.024	
1.726	1.831	1.767	1.744	1.845	1.731	1.718	1.757	20
9.340	9.476	9.690	9.645	9.922	9.733	9.917	9.607	21
10.602	9.809	9.478	9.457	9.392	9.669	10.408	10.316	22
.612	.599	.619	.646	.677	.691	.724	.647	23

Table IX (*continued*). — Summary showing Classification of Proportion of Each Class to Total for

No.	Item.	Amount, 1904.	Per cent.		
			1904	1903	1902
24	Oil, tallow, and waste for locomotives	$ 5,460,629	.409	.389	.366
25	Other supplies for locomotives	3,351,739	.251	.232	.218
26	Train service	88,237,172	6.602	6.677	6.737
27	Train supplies and expenses	20,777,084	1.555	1.552	1.500
28	Switchmen, flagmen, and watchmen	57,909,962	4.333	4.313	3.984
29	Telegraph expenses	23,362,675	1.748	1.754	1.784
30	Station service	86,339,589	6.460	6.664	6.832
31	Station supplies	10,361,992	.775	.667	.676
32	Switching charges—balance	3,985,153	.298	.244	.272
33	Car per diem and mileage—balance	20,340,343	1.522	1.400	1.480
34	Hire of equipment—balance	5,738,952	.429	.214	.180
35	Loss and damage	17,002,602	1.272	1.094	.990
36	Injuries to persons	15,838,179	1.185	1.120	1.048
37	Clearing wrecks	3,631,352	.272	.284	.221
38	Operating marine equipment	11,074,030	.829	.745	.721
39	Advertising	5,937,816	.444	.428	.429
40	Outside agencies	19,563,159	1.464	1.449	1.579
41	Commissions	822,212	.062	.044	.077
42	Stock-yards and elevators	2,738,499	.205	.057	.069
43	Rents for tracks, yards, and terminals	19,694,025	1.474	1.544	1.519
44	Rents of buildings and other property	5,103,561	.382	.411	.440
45	Stationery and printing	8,557,541	.640	.642	.622
46	Other expenses	4,726,400	.353	.376	.416
	Total	$757,372,878	56.670	55.893	54.671
	General Expenses.				
47	Salaries of general officers	$ 11,234,945	.841	.823	.925
48	Salaries of clerks and attendants	17,552,570	1.313	1.254	1.244
49	General office expenses and supplies	3,080,718	.230	.234	.249
50	Insurance	6,289,915	.471	.432	.412
51	Law expenses	6,856,870	.513	.541	.558
52	Stationery and printing (general offices)	2,272,390	.170	.175	.168
53	Other expenses	4,091,731	.306	.330	.391
	Total	$ 51,379,139	3.844	3.789	3.947
	Grand total	$1,336,476,325	100.000	100.000	100.000

Operating Expenses for the Year ending June 30, 1904, and the Years ending June 30, 1904, to 1895.

Per cent.							Average ten years.	No.
1901	1900	1899	1898	1897	1896	1895		
.361	.365	.359	.355	.374	.379	.413	.377	24
.206	.188	.177	.156	.160	.229	.200	.202	25
7.011	7.244	7.583	7.660	7.589	7.784	7.993	7.288	26
1.471	1.467	1.527	1.525	1.508	1.556	1.526	1.519	27
3.848	3.944	4.149	4.080	4.171	4.120	4.160	4.110	28
1.785	1.812	1.906	1.907	2.000	1.978	2.078	1.875	29
6.947	7.103	7.510	7.758	8.002	7.710	8.112	7.310	30
.672	.679	.696	.692	.751	.794	.876	.728	31
.319	.340	.356	.331	.327	.356	.344	.319	32
1.618	1.800	2.010	2.107	2.203	2.054	2.096	1.829	33
.161	.223	.368	.342	.249	.322	.384	.287	34
.819	.764	.734	.706	.692	.775	.784	.863	35
.911	.910	.874	.884	.874	.840	.945	.959	36
.189	.173	.147	.130	.123	.126	.130	.179	37
.862	.866	.868	.958	.934	.826	.848	.846	38
.428	.432	.438	.417	.428	.417	.429	.429	39
1.615	1.519	1.781	1.762	1.727	1.567	1.623	1.609	40
.089	.151	.194	.181	.158	.168	.154	.128	41
.075	.060	.115	.155	.140	.126	.116	.112	42
1.724	1.728	1.901	1.914	1.953	1.746	1.727	1.723	43
.440	.464	.487	.475	.501	.502	.497	.460	44
.638	.653	.627	.583	.633	.616	.589	.624	45
.510	.579	.670	.624	.587	.547	.669	.533	46
54.979	55.179	57.031	57.194	57.920	57.362	59.460	56.636	
.984	1.041	1.171	1.165	1.235	1.213	1.333	1.073	47
1.262	1.269	1.334	1.334	1.368	1.409	1.385	1.317	48
.257	.262	.292	.285	.301	.311	.315	.274	49
.384	.349	.372	.395	.436	.446	.487	.418	50
.625	.571	.710	.655	.791	.725	.806	.650	51
.161	.166	.171	.176	.163	.165	.172	.169	52
.447	.437	.471	.409	.462	.344	.457	.405	53
4.120	4.095	4.521	4.419	4.756	4.613	4.955	4.306	
100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	

itself is shown in Table IX. The variations in the principal items, especially those in which the engineer is interested, will be briefly discussed. Many of the items are directly affected by differences in operating management, and many of them are affected by such changes in alinement as an engineer may be able to make. Such items call for particular study on the part of the engineer. On the other hand, many of the smaller items are almost in the nature of fixed charges which will not be materially affected by any change which may be made by the locating engineer or by any slight change of policy in the operation of the road. Such items will only be materially affected by some radical difference in the scale of operation of the road.

Maintenance of Way and Structures.

52. Item 1. Repairs of roadway.—This item constitutes nearly one-half of the total cost of maintenance of way and structures. It might almost be said to include the maintenance of everything except such items as are specifically mentioned in the succeeding items. It includes practically everything which is usually spoken of as track-work, and also the maintenance of embankments, snow-fences, dikes, and retaining-walls. It includes the cost of maintaining frogs, switches, switch-stands and interlocking-signals. The larger part of this item is that due to labor, which is chiefly track-labor. The *percentage* of this item increased from 1895 to 1902—since then it has declined somewhat. It should likewise be noted that the average wages paid to trackmen have been increasing since 1894. The low point was reached in 1897–8 at $1.16 per day and in 1904 it was $1.33. The wages of section foremen have varied in about the same way. The average of this item for the past ten years has been 10.767%, while the total variation from this figure has been about .5% either way, the low figure occurring with one exception (in 1898) when the cost of track-labor was a minimum.

53. Item 2. Renewals of rails.—This item, being one of the largest of the single items in the total cost of track maintenance, is considered separately. Its cost is very readily determined, since it consists of figures which are easily obtainable. It includes the cost of the rails, their inspection and their delivery to some specified delivery point on the track. The distribution of the rails each to the place where it is to be used is considered as part of the track-work and its cost is included in Item 1. The item is far more variable than Item 1. Its average value for the past ten years has been 1.422%, but during that time it has varied from 1.138% to 1.676%. These extremes occurred in succeeding years. Of course such fluctuations are due chiefly to a fluctuation in the price of rails but also to a variation in the standard of maintenance. The item includes all rails wherever used, whether on main track, siding, repair track, gravel track, or on wharves or coal-docks. It even includes guard-rails, but does not include any rail attachments, such as joints, frogs, switches, etc.

54. Item 3. Renewal of ties.—This item averages over twice the cost of the renewal of rails, but the fluctuations are not quite as large a percentage of the item itself. The significance of the item corresponds closely with that of rails. It includes the cost of the ties, but not the cost of distributing them or placing them in the track. It does, however, include the cost of tie-plates and tie-plugs and also any chemical treatment which may be used. It would be expected that with the increasing scarcity of timber the cost of tie-renewals would be greater year by year, but there does not seem to be any indication of a uniform increase in cost. In fact the highest percentage during the last ten years occurred in 1898.

55. **Item 4. Repairs and renewals of bridges and culverts.** —This item includes the maintenance, cost of all bridges, trestles, viaducts, and culverts. It also includes all piers, abutments, riprapping, etc., necessary to maintaining them and the cost of operating drawbridges. The average cost of the item for ten years has been 2.461%, and the variations have been quite small with no noticeable tendency to grow uniformly greater or less. The locating engineer is but little concerned with this item, since it usually does not figure except in specific instances, which must be specifically considered in his calculations about a proposed change of line. So far as the maintenance of small bridges and culverts are concerned it would usually be sufficiently accurate to consider that a proposed change of line, involving perhaps several miles of road, would require substantially the same number of bridges and culverts, and therefore that the cost of maintaining them would be the same by either line. The error involved in such an assumption would usually be insignificant, unless there was a very large and material difference in the two lines in this respect. Under such conditions special computations should be made.

56. **Items 5 to 10. Repairs and renewals of fences, road-crossings, and cattle-guards—of buildings and fixtures—of docks and wharves—of telegraph-plant; stationery and printing, and "other expenses."**—These six items have a sum total of a little over 3%. Their fluctuations are small and are usually due to causes which are beyond the control of the engineer and which will be unaffected by any reasonable change of plans which the engineer may make. In Item 5 are included not only those things which are specifically mentioned but also those structures which in general are not directly affected by the running

of trains. For example, road crossings include not only the maintenance of highway crossings at grade but also overhead highway crossings and whatever a railroad may have to pay for the maintenance of a bridge by which another railroad crosses it. On the other hand, the maintenance of a bridge by which a railroad crosses another road (highway or railroad) is charged to bridges. Item 6 includes the cost of maintaining all buildings which are used to facilitate transportation, such as roundhouses and coaling-stations, water stations, sand-houses, signaling-towers, and passenger and freight stations. It also includes such miscellaneous structures as turntables and track-scales. Fixtures include cranes, derricks, office furniture, etc. Item 6 is a large one with considerable fluctuation, but railroad location has little or no influence on it. A possible exception is noted at the end of § 86. Items 7 to 10 are exceedingly small and the engineer has still less chance of influencing them in any way.

Maintenance of Equipment.

57. Item 11. Superintendence.—The item averages about two-thirds of one per cent and has so little fluctuation under ordinary conditions that it may almost be considered as a fixed charge. It includes those fixed charges in superintendence which do not fluctuate with small variations in business done. It includes the salaries of superintendent of motive power, master mechanic, master car-builder, foreman, etc., but does not include that of road foreman of engines nor enginemen. Although the item will vary with the general scale of business on the road, it does not fluctuate with it and hence will not usually be influenced by any small changes in alinement which the engineer may be considering.

58. Item 12. Repairs and renewals of locomotives.—This subject will be treated at greater length in Chapter VII, Motive Power. The item is of interest to the locating engineer because he must appreciate the effect on locomotive repairs and renewals of an addition to distance. This will be further considered in Chapter XII. A large part of the repairs of locomotives are due to the wear of wheels, which is largely caused by curvature. Therefore the value of any reduction of curvature is a matter of importance, and this will be considered in Chapter XIII. A considerable portion of the deterioration of a locomotive is due to grade, and the economic advantages of reductions of grade will be considered in Chapters XIV to XVII.

This item includes the expenses of work whose effect is supposed to last for an indefinite period. It does *not* include the expense of cleaning out boilers, packing cylinders, etc., which occurs regularly and which is charged to Item 21, roundhouse-men. It does include all current repairs, general overhauling, and even the replacement of old and worn-out locomotives by new ones to the extent of keeping up the original standard and number Of course additions beyond this should be considered as so much increase in the original capital investment. As a locomotive becomes older the *annual* repair charge. becomes a larger percentage on the first cost, and it may become as much as one-fourth and even one-third of the first cost. When a locomotive is in this condition it is usually consigned to the scrap-pile, the annual cost for maintenance becomes too large an item for its annual mileage. The effect on expenses of increasing the weight of engines is too complicated a problem to be solved accurately, but certain elements of it may be readily computed. While the cost of repairs is greater for the heavier engines, the increase is only about one-half as fast as the increase in weight—some of the subitems not being increased at all. This will be further discussed in Chapter VII.

59. Items 13, 14, and 15. Repairs and renewals of passenger-cars—of freight-cars—and of work-cars.—Many of the economic features of car construction, especially the effect of modern improvements, such as friction draft-gear, automatic couplers, and air-brakes, will be considered in Chapter VIII. Such figures will be utilized in considering the effect on car repairs of additional distance, of variations in curvature, and of grade as discussed in Part III. During the past five years there has been a gradual reduction in the percentage of this item for passenger-cars, but such a period is too short to determine whether this reduction is merely a chance fluctuation or an indication of a policy which will continue. On the other hand, the repairs and renewals of freight-cars have increased rather than diminished. The *fluctuations* of this item are largely due to accidents rather than to any line of policy under the control of the engineer. It should be understood that for these items, as well as the previous item, the renewal of rolling stock generally means the construction of higher-grade locomotives and higher-grade cars. When this is done the difference in cost between the higher-grade, and probably more expensive, construction and the former cheap construction should be considered as an addition to the capital account rather than a charge against operating expenses. The enormous increase in the movement of freight during the last few years has required a corresponding increase in freight-car equipment. Some roads have been charging up the full cost of the renewing of their old-fashioned light-weight equipment with more expensive equipment under the head of operating expenses, and it is quite possible that a portion of the increase in Item 14 is due to this policy.

60. Items 16, 17, 18, and 19. Repairs and renewals of marine equipment—of shop machinery and tools; stationery and printing; other expenses.—The location of the road along the line has no connection with the maintenance of marine equipment. The maintenance of shop machinery and tools can only be affected as the work of repairs of rolling stock fluctuates, and of course in a much smaller ratio. No change which an engineer can effect will have any appreciable influence on this item.

The other items are too small and have too little connection with location to be here discussed, except as it may be considered that they vary with train-mileage, which an engineer may influence (see Chapter XXIII, Grades).

Conducting Transportation.

61. Item 20. Superintendence.—This item averages about 1.75% and is only subject to small fluctuations. It will not be appreciably varied by any change of policy which the engineer may adopt.

62. Item 21. Engine- and roundhouse-men.—This item includes the wages of engineers, firemen, and all men employed around engine-houses except those making such repairs as should be charged to the maintenance of equipment. A distinction is made between the two classes of roundhouse work on engines, one of which is considered the regular routine work, such as cleaning boilers, etc., and the other comprising those larger operations which may be considered as "maintenance of equipment." The roundhouse-men are usually paid by the day, but their total wages amount to about 9% of the total of Item 21. On the other hand, enginemen are necessarily paid by the trip, except on the very small railroads. On very short roads, where a train crew can make two, three, or even four complete round trips per day, they may readily be paid by the day, so many round trips being considered as a day's work, but on roads of great length, where all trains, and especially freight-trains, are run day and night, week-day and Sunday, all trainmen are necessarily paid by the trip or, as it is more usually expressed, by the "run." It is generally found convenient to divide the road into "divisions" which are approximately 100 miles in length. According as the division is greater or less than 100 miles, it is designated as a $1\frac{1}{8}$ run, $1\frac{1}{4}$ run, or perhaps $\frac{7}{8}$ run. The enginemen will then be paid according to the number of runs made per month. There is a considerable fluctuation in the average wages paid in different sections of the United States, as is shown by the tabular form given below, in which the "groups" refer to the sections into which the country has been divided by the Interstate Commerce Commission, as is shown in Fig. 4. This tabular form may be of some assistance in showing the average daily compensation which must be allowed for in the various sections of the country.

AVERAGE DAILY COMPENSATION BY GROUPS—1904.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	U. S.
Enginemen .	$3.55	$4.06	$3.99	$4.19	$4.25	$3.98	$4.17	$4.28	$4.32	$4.97	$4.10
Firemen. . . .	2.02	2.33	2.33	1.95	2.09	2.39	2.47	2.62	2.56	2.97	2.35

The actual wages paid to enginemen have been growing almost steadily between 1894 and 1904, the increase in that time being about 14%. Firemen are paid about 55% to 60% as much as enginemen, but their wages have likewise been steadily increasing from 1894 to 1904. In spite of this very large increase in wages and therefore absolute increase in the total amount paid, the *percentage* of Item 21 has in general declined between 1894 and 1904, as is shown by Table IX in the first part of the chapter.

This shows that in spite of the very considerable increase in wages the cost of running a railroad has increased in a still faster ratio. The fluctuations of this item are of importance to the locating engineer in discussing the economics of differences in distance. This feature will be more fully discussed in Chapter XII.

63. Item 22. Fuel for locomotives.—This item includes every subitem of the entire cost of the fuel until it is placed in the engine-tender. The cost therefore includes not only the first cost at the point of delivery to the road, but also the expense of hauling it over the road from the point of delivery to the various coaling-stations and the cost of operating the coal-pockets from which it is loaded on to the tenders. Even though the cost may be fairly regular for any one road, the cost for different roads is exceedingly variable. There has been a steady increase in the percentage of the cost of this item per train-mile from 1897 to 1904. The item amounted to nearly 12% of the total operating expenses in 1904, and required an actual expenditure of nearly $159,000,000. It is the largest item in the whole cost of railroad operation. Although some roads, which traverse coal-regions and perhaps actually own the coal-mines, are able to obtain their coal for a cost which may be charged up as $1 per ton or less, there are many roads which are far removed from coal-fields which have to pay $3 to $4 per ton, on account of the excessive distance over which the coal must be hauled. Unfortunately the figures published by the Interstate Commerce Commission do not show the variations in the percentage of this item in the different groups. In the various chapters of Part III will be shown the effect on fuel consumption of the several variations in location details. The great importance of this item requires that it shall be thoroughly understood and studied by the engineer. It will be shown, contrary to the commonly received opinion, that the fuel consumption is quite largely independent of distance and even of the number of cars hauled.

64. Items 23, 24, and 25. Water-supply; oil, tallow, and waste; other supplies for locomotives.—Although the percentage cost of the water-supply has fluctuated considerably during ten years, there is but little indication of any permanent increase or decrease in the percentage. It is quite largely a fixed charge, since it is frequently furnished by municipalities at flat rates. There is but little reason to anticipate any increase in the cost, except as the general increase in the scale of expenditures might cause an increase in the absolute cost per train-mile. Of course this would not affect the *percentage*, although, since the cost per train-mile has been steadily increasing, a constant percentage will indicate a constantly increasing cost per train-mile. The other items of locomotive supplies are very small and are usually found to fluctuate very closely with the variations in the cost of water. Since the consumption of all these supplies will vary nearly as the engine mileage, the engineer is concerned with them directly to the extent to which he may change to the engine mileage.

65. Item 26. Train service.—This item is one of the largest single items and includes in general the wages of all the train-hands except the engineman and fireman. As in the case of the engineman the train-hands are usually paid according to the number of runs. The item is therefore of importance to the locating engineer from the one standpoint of distance, and even then only when the variation of distance, which is considered, will affect the classification of the run and therefore the rate of pay for that run. As in the case of the engineman and fireman there has been an almost uniform increase in the average daily compensation paid to these trainmen from 1894 to 1904. The statistics of the Interstate Commerce Commission give not only the average wages paid to conductors and other trainmen for the whole United States, but also the average for each group. As might have been expected the figures fluctuate considerably with the different groups, but it will be found that the fluctuations vary quite regularly with the fluctuations in receipts and operating expenses per train-mile in the different sections. This means that the general scale of wages and of living expenses in different parts of the country vary approximately in the same ratio.

66. Item 27. Train supplies and expenses. — These items, which average about 1.5%, include the large list of consumable supplies, such as lubricating-oil, illuminating-oil or gas, ice, fuel for heating, cleaning materials, etc., which are used on the cars and not on the locomotives. The consumption of some of these articles is chiefly a matter of time. In other cases it is a function of mileage. The effect of changes which an engineer may make on this item will be considered when estimating the effect of the changes.

67. Items 28, 29, 30, and 31. Switchmen; flagmen and watchmen; telegraph expenses; station service; and station supplies.—The expenses chargeable under these items are very obvious from the titles. Many subitems, which are very small or which are of occasional or accidental occurrence, are also included under these items for lack of a better classification. The largest single item of these four is that of station service, which has averaged 7% for the last ten years. Although it may have no special significance, the percentage of this item has been declining for seven or eight years past. In general the items are proportional to the general scale of business of the road, and are very largely independent of small fluctuations in business or of any changes which an engineer may be able to make.

68. Item 32. Switching charges.—Where two or more railroads intersect there will be a considerable amount of shifting of cars, chiefly freight-cars, from one road to the other. This shifting at any one junction may be done entirely by the engines of one road or perhaps by those of both roads. A portion of the expense of this work is charged up against the other road by the road which does the work. The total amount of this work is carefully accounted for by a clearing-house arrangement, and the balance is charged up against the road which has done the least work. The item is very small, is fairly uniform year by year, and is seldom, if ever, affected by changes of alinement.

69. Item 33. Car per diem and mileage—balance.—This item is a charge paid by one road to another for the use of cars, which are chiefly freight-cars. To save the rehandling of freight at junctions, the policy of running freight-cars from one road to another is very extensively adopted. Since the foreign road receives its mileage proportion of the freight charge, it justly pays to the road owning the car a rate which is supposed to represent the value of the use of the freight-car for the number of miles traveled. The foreign road then loads up the freight-car with freight consigned to some point on the home road and sends it back, paying mileage for the distance traveled on the foreign road, a proportional freight charge having been received for that service. All of these movements of freight-cars are reported to a car association, which, by a clearing-house arrangement, settles the debit and credit accounts of the various roads with each other. Such is the simple theory. In practice the cars are not sent back to the home road at once, but wander off according to the local demand. As long as a strict account is kept of the movements of every car, and as long as the home road is paid the charge which really covers the value of lost service, no harm is done to the home road, except that sometimes, when business has suddenly increased, the home road cannot get enough cars to handle its own business. The value of the car is then abnormally above its ordinary value, and the home road suffers for lack of the rolling stock which belongs to it. Formerly such charges were paid strictly according to the mileage. This developed the intolerable condition that loaded cars would be run onto a siding and left there for several days, simply because it was not convenient to the consignee to unload the car immediately. On the mileage basis the car would be earning nothing, and, since the road on which the car then was had no particular interest in the car, the car was allowed to stand to suit the convenience of the consignee. To correct this evil a system of per-diem charges has been developed, so that a railroad has to pay a per-diem charge for every foreign car on its lines. To reduce this charge as much as possible the railroads compel consignees, under penalty of heavy demurrage charges, to unload cars promptly. The running of freight-cars on foreign lines is now settled almost exclusively on the per-diem basis, but the earning of passenger-cars over other lines, as is done on account of the advantages of through-car service, as well as the running of Pullmans and other special cars, is still paid for on the mileage basis. To the extent to which this charge is settled on the mileage basis, any change in distance which the engineer may be able to effect in the length of the road will have its influence on this item, but when the freight-car business, which comprises by far the larger part of the running of cars over foreign lines, is settled on the per-diem basis no changes in alinement which the engineer may make will have any influence on the item. The item averages about 1.8%. For the past five years it has been considerably less than for the previous five years, which apparently indicates that the strict enforcement of the regulations regarding per-diem charges have made the railroads far more careful in the conduct of such business, and hence has reduced the charge.

70. Items 35, 36, and 37. Loss and damage; injuries to persons; clearing wrecks.—These expenses are fortuitous and bear no absolute relation either to the number of miles of road or the number of train-miles. While they depend largely on the standards of discipline on the road, even the best of roads have to pay some small proportion of their earnings to these items. While we might expect that a road with heavy traffic would have a larger proportion of train accidents than a road of light traffic, it is usually true that on the heavy traffic roads the precautions taken are such that they are usually freer from accidents than the light traffic roads. During recent years there has been a very perceptible increase in the percentages of these items, particularly in the compensations paid for "injuries to persons." The increase in this item coincides with the increase already noted in the number of passengers killed during recent years. The possible relation between curvature and accidents has already been discussed, but otherwise the locating engineer has no concern with these items.

71. Items 38 to 53.—All of the remaining items, as stated in Table IX, are of no concern to the locating engineer. They are either general expenses, such as the salaries of general officers, insurance or law expenses, or are special items, such as advertising or the operation of marine equipment which will not be changed by any variations in distance, curvature, or grades which a locating engineer may make. There is therefore no need for their further discussion here.

72. Estimation of the effect on operating expenses of a change in alinement.—It has already been shown that the cost of a train-mile is marvelously uniform on roads of varying character. The cost of running a train one mile has therefore been taken as the unit of value on which to base calculations as to the effect of changes in alinement. The general method is to take up each item in turn of the cost of operating trains, and to estimate the effect of a change in alinement on each item of expense. Some of the items are changed very materially. Others are practically unaffected. By careful study of the situation, it is usually possible to estimate with reasonable accuracy that each proposed change in alinement would affect each item by a certain percentage of the average value of that item. If we then multiply the normal percentage of each item by the total percentage by which the item is affected and add the products, we will have the percentage of the average cost of a train-mile which shows the effect of one mile of such change in alinement. If we multiply this percentage by the average cost of a train-mile, we will then have the cost for each train-mile operated of so much change in alinement. Multiplying that value by the number of trains run per day or per year, we will then have the daily or annual cost of that change of alinement for that road. If, for example, we find that a certain change in alinement would make a saving of 24 c. for each train passing over the road, then the annual saving, if there were 3000 trains per year, would be $720. But an annual saving of $720 would justify the expenditure of $14,400 if interest were at 5%. If, therefore, the change can be made for an expenditure of about $14,000, it will probably be justified.

73. Reliability of such estimates.—It may be argued that such calculations are utterly useless, because the data on which the computations are based are variable and to some extent non-computable, and therefore no dependence can be placed on the calculations. This is true to the extent that it is useless to claim any great precision in the computation of the value of any proposed change of alinement. In the numerical case suggested above it is assumed that the saving amounts to only $720 per year. The cost of making the change is very easily computed. If it is found that it can be done at a total expenditure of say $3000, then there is hardly any question of the advisability of making the change, for, with all the allowance which can reasonably be made in the method of computing the effect of the change, we can be sure that the final result is not in error by several times the true result. The question is not so much as to whether our computed capitalized value, $14,400, is mathematically precise or even correct to within 10%. The method of computation gives a value which is fairly close and which will give a rational measure of the advisability of making the change. If the cost of the improvement very nearly equals the computed capitalized value, then it will probably make but little difference whether the improvement is made or not. Such a question would then depend more on the difficulty of raising money for the improvement. Also, if it is shown that the cost of making the improvement is far greater than the capitalized value of the improvement as computed, then there is hardly any doubt that the improvement is not justifiable.

To express the above question more generally, in every computation of the operating value of a proposed improvement, it may always be shown that the true value lies somewhere between some maximum and some minimum. Closer calculations and more reliable data will narrow the range between these extreme values. According as the interest on the cost of the proposed improvement is greater or less than the mean of these limits, we may judge of its advisability. The range of the limits shows the uncertainty. If it lies outside of the limits there is no uncertainty, assuming that the limits have been properly determined. If well within the limits either decision will answer, unless other considerations determine the question. And so, although it is not often possible to obtain precise values, we may generally reach a conclusion which is unquestionable. Even under the most unfavorable circumstances the computations, when made with the assistance of all the broad common sense and experience that can be brought to bear, will point to a decision which is much better than mere "judgment," which is responsible for very many glaring and costly railroad blunders. In short, Railroad Economics means the application of systematic methods of work *plus* experience and judgment rather than a dependence on judgment unsystematically formed. It makes no pretense to furnishing mechanical rules by which all railroad problems may be solved by any one, but it does give a general method of applying principles by which an engineer of experience and judgment can apply his knowledge to better advantage. To the engineer of limited experience the methods are invaluable; without such methods of work his opinions are practically worthless; with them his conclusions are frequently more sound than the unsystematically formed judgments of a man with a glittering record. But the engineer of great experience may use these methods to form the best opinions which are obtainable, for he can apply his experience to make any necessary local modifications in the method of solution. The dangers lie in the extremes, either recklessly applying a rule on the basis of insufficient data to an unwarrantable extent, or, disgusted with such evident unreliability, neglecting altogether such systematic methods of work.

CHAPTER VII.

MOTIVE POWER.

Economics of the Locomotive.

74. Total cost of power by the use of locomotives.— The total cost of motive power by the use of locomotives must be determined by a consideration of the first cost of the locomotive, the cost of maintaining it in condition for work, and the cost of operating it. Considering the variable life of locomotives of different cost, we must consider, instead of the first cost of the locomotive, the average annual cost which will be the equivalent of the actual total cost through the period of the life of the locomotive. In general it may be said that the heavier and more expensive locomotives have been found most economical, considering the ton-miles of hauling which they accomplish during their total life, than the lighter and less expensive locomotives, but the economics of any type of locomotive can only be determined by a consideration of all the terms involved. As a general statement we may say that a locomotive is the cheapest which will haul a ton-mile over any combination of grades and curves at a less *total cost* (considering all items) than will be charged to any other engine of its class. Strictly speaking, even the above test should be applied only to compare the locomotives of one class, and perhaps only to freight-locomotives. Passenger-locomotives usually have the requirement of high speed, which cannot be obtained except at a proportionate sacrifice in hauling capacity. But it is not even possible to consider that the test of any one locomotive will be an accurate measure of the efficiency of that type, since it is often found that locomotives, which are built at the same shop, according to identical plans and used in the same kind of service, will have a very different history regarding shop repairs, fuel and supplies consumed, etc. Of course there is a reason for this in each case, and the blame is ordinarily laid on the enginemen. While this is frequently justifiable the engine-builder may also be somewhat to blame. A summation of the percentages of Items 12, 21, 22, 23, 24, and 25 in the classification of operating expenses, referred to in Chapter VI, shows that the average for ten years is as follows:

TABLE X.—COST OF MAINTENANCE AND OPERATION OF LOCOMOTIVES, 1894–1904.

	Percentage of total cost of a train-mile.	Cost in cents per train-mile.
Item 12—Repairs and renewals of locomotives....	6.538	6.983
" 21—Engine- and roundhouse-men—wages. ..	9.607	10.260
" 22—Fuel for locomotives..................	10.316	11.019
" 23—Water-supplies for locomotives.........	.647	.692
" 24—Oil, tallow, and waste for locomotives...	.377	.403
" 25—Other supplies for locomotives..........	.202	.216

The average cost per train-mile for the same ten years equals 106.813 c. If we multiply these percentages by this average cost we obtain the average cost in cents per train-mile for these various items, as given in the last column of Table X.

75. Renewals of locomotives.—If there were no variations in the types and the cost of locomotives, as built from year to year, it would be comparatively simple to charge the entire cost of renewals as operating expenses;

but since there has been, and perhaps always will be, a development in the type of locomotive used, the newer being usually more costly, but in spite of their added cost being really more economical, we find that the cost of the new locomotives is constantly greater. The strictly proper method would be to charge up the excess cost of the new locomotive as an addition to the property of the road.

There is quite a difference in the policies of roads, especially when we compare the roads of this country and of England with respect to the character of work and materials used. In general it may be said that the locomotives in England last many years longer than they do in this country, and that there are now some locomotives still in use which have been in service for forty or fifty years. In America the policy is different. An engine is built with the expectation that in twenty years or perhaps less it will be in the scrap-heap. While it is in service it is worked very hard, and its annual mileage is very much greater than the mileage of an English locomotive. By the time it is thrown into the scrap-heap it has a mileage perhaps greater than an English locomotive with twice its life. The locomotive is then replaced with a newer type which is more economical, while the English locomotive is perhaps considered too valuable to throw away, and is therefore continued in service with less economy than would be obtained from a more modern engine. Of course the relative economy of these two methods may be open to discussion, but it is claimed that the American method of quickly obtaining the maximum of usefulness of a locomotive and then throwing it away produces an actual economy in the cost per ton-mile. The comparison of the two methods is somewhat complicated, owing to other conditions, such as cost of fuel, labor, etc., which would modify the apparent result and render the true result more uncertain. A. M. Wellington stated several years ago that the average mileage life of English and European locomotives was about 450,000 to 500,000 miles, and at the same time gave the life of American locomotives as 700,000 miles. The practice of railroads at the present time is to obtain a far higher railroad mileage, the mileage per year frequently amounting to 50,000, and records of 8000 to 10,000 miles per month for several months are very common with passenger-engines. If we consider that any given locomotive will have a life of twenty years and that its mileage per year will average 50,000 miles, thus making a total of 1,000,000 miles during its life, the railroad could create a fund by an annual payment which at compound interest would produce the total cost of renewing the locomotive at the end of twenty years, or at least of furnishing an amount equal to its present cost. Tables show us that 3 c. per year at compound interest for twenty years will produce $1, or, if we consider the cost of the locomotive as $10,000, $300 per year, compounded at 5%, will produce $10,000 at the end of twenty years. If the locomotive has an annual mileage at 50,000, we should charge $\frac{\$300}{50,000}$, or 0.6 c. per mile as the item to take care of the regular renewals. Of course such items would only apply to the cost of renewing that engine with one of equal cost. The probabilities are that the new engine will actually cost more money. The economics of heavier engines will be discussed later.

76. **Repairs of locomotives.**—The term "renewals of locomotives" applies only to the literal substitution of a new locomotive for one which has been sent to the scrap-heap. Repairs are divided into two classes: general repairs and current repairs which are usually made in a roundhouse. The term "general repairs" applies to the more expensive work of repairing which is done in one of the general repair-shops of the road rather than in the roundhouse. Some

roads consider that the repairs to a locomotive should be considered as general repairs if the amount of work to be done at any one time exceeds a certain figure, say $750, but as such a method of classifying repairs is purely arbitrary and depends to some extent on the amount of work that is done at the roundhouse in keeping the engine in condition, any comparison between the figures of two roads are almost useless. It is ordinarily expected that a passenger-locomotive should make 120,000 miles and a freight-engine 80,000 miles between consecutive assignments to the shop for general repairs, but even such figures are of little significance, except that, if a locomotive should be sent to the shop without having made some such mileage since the last visit, it would imply that there had been some mismanagement (barring accidents) for which some one was responsible. The term "current repairs" includes all the smaller repairs which are not considered of sufficient importance to demand a general overhauling of the locomotive. The figures reported by various roads for the cost of current repairs per engine handled average something over $1 per engine. Taking the figures in connection with the mileage-run it would show an average cost of from one to two cents per mile-run. Under very unfavorable conditions the total cost of general and current repairs may amount to from 10 to 15 c. per mile-run. Considering the average figure for the country given in a previous section (Item 12, 6.983 c.), if we deduct .6 c. (or even a little more) as the cost for renewals we have left about 6 c. as the total average cost of the country of the general repairs. This seems to agree very closely with the statistics given by a certain road that the average cost of engine repairs per freight-engine mile during a period of seven years varied from 5.88 to 6.82 c., or an average of 6.30 c. per freight-engine mile. Another road, which gives the cost of freight-engine repairs as 7.22 c, per engine-mile, quoted at the same time the cost of passenger-engine repairs as 5.60 c. per engine-mile. If, however, we consider these figures on the basis of the work accomplished by the locomotives, we have another indication of the large economy in the use of heavy engines hauling heavy trains. In the last-mentioned case the costs were 22.88 c. for passenger-engines and 7.73 c. for freight-engines *per thousand ton-miles;* but the freight-trains were more than four times as heavy as the passenger-trains, so that, although the freight-engines cost far more than the passenger-engines *per engine-mile,* the cost *per ton-mile* was far less. It is usually found that compound engines cost much more per engine-mile than simple engines of the same capacity, and that the comparison is made still worse because their annual mileage is apt to be less, owing to their standing so much time in the repair-shops. On account of the very great variety of engines, the cost of engine repairs per engine-mile is very different for different types of engines, and the cost per ton-mile is likewise very variable. Mr. G. R. Henderson has suggested that the cost of repairs may be represented by the very simple formula of 1 c. per ton of tractive force per mile plus 1 c. per engine-mile. In this statement, however, he considers the term "tractive force" to be the average force which is actually exerted, and not the maximum tractive power. For example, he considered a passenger-engine, whose tractive force amounts to ten tons, and assumed that the actual tractive force exerted by it will not *average* more than 40% of this maximum. For the above case the assumed cost of repairs would be 40% of 10 or 4×1 c.+1 c. for each mile-run, making a total of 5 c. per mile. This method is applied to pusher-engine service as follows: He assumes an engine with 40,000 pounds tractive force, which is exerted to its full capacity in running up-hill, and which returns down the hill without the use of steam. Applying the principle to a grade twenty miles long, the item chargeable to repairs for the up-hill run would be 20×20 c.+20 c. or $4.20. For the down-hill trip we would have merely 20×1 or 20 c., making a total of $4.40 for the 40-mile round trip, or an average of 11 c. per mile. In the case of pusher service it is generally correct to assume that the engine is working to its full capacity in climbing the hill, and that it does not have to use steam in going down. When we apply such a formula to the undulating grades on an ordinary road, it becomes very difficult to determine the proportion of the total possible tractive force which is actually exerted. Usually we can only make a very approximate assumption.

77. **Wages of engine- and roundhouse-men.**—Enginemen and firemen are usually paid by the "trip," a trip implying a distance of 100 miles. If a division happens to be somewhat less than 100 miles, it is usually considered to be 100 miles, and the men will be paid according to the number of "trips" made per month. If the run is more than 100 miles a proportionate amount is usually added per trip. The wages paid, however, vary considerably, according to the tonnage of the engine, it being considered that the heavier engines require a better grade of service and possibly a more dangerous service. But, beside the regular schedule allowances paid for regular service, there is a specific allowance of 25 c. per hundred miles above the regular rate for way-freight trains. The enginemen for pusher-engines are paid for a day of 12 hours or less with some increased pay for overtime work. Switching enginemen are also paid by the day. Enginemen on engines running light are paid the same rate as those on passenger-engines. Enginemen are usually paid somewhat less during their first year of service as enginemen than they are during succeeding years. On one road, with a very complete schedule for payments of different kinds

of service, all men with regular assignments are guaranteed 2600 miles per month unless they are responsible for loss of time and mileage. The methods for allowing for overtime are quite varied. It is frequently specified that no overtime shall be allowed for enginemen in passenger service unless the time of the trip exceeds eight hours. For freight service the limit is made ten hours. This is practically on the basis of running a freight-train at an average speed between terminals of 10 miles per hour, assuming that the division is 100 miles long. In order to equalize the differences in the difficulty in handling trains on different divisions, due to various sources, such as extraordinarily heavy grades, etc., it is usual for the railroad companies to arbitrarily consider the division to have a certain number of miles somewhat in excess of the actual mileage. This increase is sometimes as much as 25% and must practically be considered as merely adding so much to the engineman's wages per mile, although the amount added is variable. There is also a very large amount of mileage added on many roads where the grades or the amount of traffic in opposite directions is very different, due to the amount of light-engine mileage. This applies particularly to freight service, although it may apply to some extent to passenger service. A consideration of the above data will show that the wages assignable to the enginemen for each mile actually run, and especially for a mile of distance which might be added or cut out, is very different from the average wages actually paid to them. The average daily compensation actually paid to enginemen and firemen in the different parts of the United States during the year 1904, as compiled by the Interstate Commerce Commission, has already been given in § 62. The average percentage of operating expenses assignable to enginemen and roundhouse-men for the year 1904 was 9.386%. Multiplying this by the average cost of a train-mile for the same year (131.375 c.), we have 12.331 c. per mile. This expense represents the total assignable to the three classes of enginemen, firemen and roundhouse-men. The term "roundhouse-men" here includes hostlers, wipers, oilers, cleaners, ash-pit men, dispatchers, call-boys, general roundhouse-men, and men employed in the superintendence of the roundhouse. The actual per-diem wages paid them is of course variable. The total amounts paid in 1904 to each of these three classes (engineers, firemen, and round house-men) were $68,946,543, $40,463,040, and $16,031,241 respectively. The percentages of these subitems to the total item are 54.9%, 32.3%, and 12.8% respectively. Multiplying these first two percentages by the total cost of the item in cents per train-mile, we have average figures for the wages paid to enginemen and firemen per train-mile, which are 6.78 c. and 3.98 c. respectively. As a matter of fact, the average compensation paid per actual mile traveled is far greater than this, on account of the excess allowed to these men for overtime, constructive mileage, etc., which is almost invariably compensated for to the advantage of the men rather than to the company. For example, if a freight-train is delayed for several hours, the men are paid for their time (whatever may be the basis), while the delay is an absolute loss to the company.

78. Fuel for locomotives.—It should not be forgotten that the cost of fuel per ton at the mine, or even the cost when delivered at the coaling-stations, is by no means the measure of the economy in fuel. The value of fuel per ton depends on its heating capacity, and varies from the value of wood (which is still used in some places where it is exceptionally cheap) as fuel, up through various grades of coal to the use of oil, which furnishes more heat per ton than any other grade of fuel. For general use we may ignore these two extremes, since in nearly all localities wood for fuel is not only costly, but of comparatively little value. At the other extreme, oil for fuel is almost impracticable, except where the Texas oils, whose composition gives them a particularly high fuel value, are sufficiently convenient to make their use economical. One ton of fuel-oil has a heat equal to about 1½ tons of good coal or two tons of lignite. The saving in hauling of fuel, the ability to regulate the firing so as to produce a uniform heat, the actual saving in repairs to the fire-box, the utter absence of expenses incident to ash-handling plants, combine to give this method an economy which is even greater than would have been indicated by the comparative cost in cents of evaporating 100 pounds of water.

It sometimes happens that it will pay to haul coal from a more distant source, considering the price which is paid for it, rather than use a coal which is mined much nearer, because the actual amount of ton-miles of energy produced may be greater with the more expensive coal. For example, the values of different fuels have been carefully determined and classified according to the number of ton-miles which can be obtained per pound of coal. A few of these values, which, however, must be considered as *average* values, are as follows: 7.00 for Pennsylvania anthracite, West Virginia New River semi-bituminous, and cannel coal; 4.35 for Iowa lignite; and 4.25 for Colorado lignite slack. After all, the real question is to determine how to get the most heat for an expenditure of $1.00 at the coaling-stations. Since the cost of hauling must be included, any set of values made out for one locality are almost worthless for any other locality. As an example, a few values are extracted from some computations made by W. H. Bryan as to the real value of three grades of coal in St. Louis.

It may be observed from the following tabular form that for a coaling-station located at St. Louis the common

Kind of coal.	Cost per ton.	B. T. U. in one pound.	Cost of evaporating 100 lbs. of water.
Anthracite	$6.75	14,000	31.8 c.
Pocahontas bituminous	4.75	12,500	24.87
Common slack	.90	10,000	7.25

slack obtainable in that locality is by far the cheapest coal to use, regardless of its cost per ton. There is one slight compensation which reduces the apparent disadvantage of these figures. The anthracite coal will produce 40% more heat per pound than the common slack, and therefore the expense of hauling the extra weight of slack in order to produce a given amount of energy from the coal, as well as the necessity for re-coaling more frequently with the cheaper grade of coal, gives the anthracite coal an advantage which would make it the more economical coal if the values given in the last column were equal or nearly so. Of course in the above case those advantages are utterly swallowed up by the cheapness of the common slack.

In computing the real cost to a railroad of the fuel which it uses, the cost of the coal to the point where it is delivered to the road from another railroad is but an item of the total. There must be added to this the real cost to the road of hauling it from the point of delivery to the various coaling-stations. The actual cost of this will of course vary with the different roads, but it will seldom be less than ½ c. per ton-mile, which is the same as adding 50 c. per ton to the cost of the coal for each hundred miles it is hauled from the point of delivery.

Handling the coal at the coaling-station adds another item to its real cost to the road. The old-fashioned method of shoveling from a coal-car to a platform or bin, and from there again shoveling into a tender, will add at least 25 c. per ton to the cost of coal. The various devices for handling coal cheaply, although they reduce the cost of handling the coal, add an interest charge to pay for a more or less expensive coal-handling plant. The cost of handling coal by means of the modern coaling-station will usually average 3 c. per ton, and it is easily demonstrable that such a method is economical even to the point of paying the interest and maintenance on the cost of the plant, provided the business of the road is sufficiently large to justify such a plant.

79. **Water-supply—impurities.**—The desired qualities in the water-supply must be the first consideration. While in general it may be said that water which is suitable for drinking purposes is suitable for locomotive-boilers, even this statement cannot be taken absolutely. A catalogue of the desired qualities in the water-supply can best be stated by describing the objectionable qualities. It is popularly supposed that an absolutely pure distilled water would be the ideal type of water to use. Apart from the high cost of distillation, distilled water is actually objectionable, since it attacks the iron of the boiler quite rapidly and causes it to rust. The purer the water the more quickly will it attack the iron. A second objectionable quality of water is that caused by the presence of carbonates of lime or magnesia. When water containing these carbonates is boiled, the carbonates are deposited on the surface of the boiler, and since they are poor conductors of heat, the efficiency of the boiler is reduced on account of the lack of heat-conductivity of the scale. This form of scale, however, is not hard and is readily washed out, but such impurities in the water cause trouble and expense in proportion to the amount of them. The sulphates of lime and magnesia are far more dangerous. They deposit on the surface of the boiler in a very hard scale, which is removed with great difficulty. The difficulty of removing them may cause the washing-out process to be ineffec-

tive, unless very thorough, and the hard scale may be allowed to accumulate until it becomes very thick. In such a case the situation becomes actually dangerous, since the scale is a very poor conductor of heat. Since the intense heat of the fire is not readily transferred to the water, the iron will become overheated until it may actually soften and give way, causing an explosion. The dangerous effect of such water, and the great difficulty of removing the scale formed by these sulphates, render such waters very undesirable.

Water sometimes contains sulphuric acid, especially if it has drained out of a coal-mine. Other acids may occasionally be found, owing to the contamination of the source of supply by some industrial works. These acids will corrode the iron in the boiler and soon cause deterioration.

One of the most common difficulties with boiler-water is that caused by the presence of the sulphate or chloride of sodium or the chloride of calcium. The presence of these chemicals produces what is known as "foaming." Although the steam-pipe running from the boiler to the cylinder is led from the dome of the boiler, which is purposely made as high as possible above the surface of the water, the foaming of the water will carry more or less liquid water into the steam-pipe and from thence to the cylinders. This results in broken cylinder-heads and pistons, broken valves, and many forms of destruction of the machinery. To avoid this effect when using foaming water, the engineer or fireman will keep the water as low in the boiler as he dares, in order that the surface of the water shall be as far as possible below the dome. In the endeavor to accomplish this, too little water may be left over the crown-sheet, which becomes overheated, and the fire-box is ruined even if the boiler does not explode.

On account of the many evils resulting from impurities, as described above, railroads now generally follow the policy of submitting all proposed sources of water to a thorough chemical analysis, in order to determine their qualities. The actual evils resulting from the use of impure water, which show themselves in the expense accounts in excessive repair charges for the repairs of boilers, fire-boxes, leaky tubes, with an occasional boiler explosion, justify the expenditure of considerable sums of money to obtain suitable water-supplies. The very large increase in recent years in the number of small municipalities which have constructed water-works for their own use, has resulted in many railroads relying on such water-supplies for the supply of their local water-stations. Although it is generally possible to obtain by pumping from a private well or a stream a sufficient quantity of water at a much lower price per gallon than would usually be charged by the municipality, nevertheless it is generally advisable, especially in view of the danger of the future contamination of a well or stream, which may at th present give a suitable supply, to utilize these municipal supplies.

The above paragraphs describe the evils of a contaminated water-supply. The requirements of operation, which necessitate the location of water-stations at approximately fixed places on the line of the road, leave no alternative but to use such water as is obtainable and, if necessary, to treat it chemically before it is used, so that it will not be injurious. In the early history of the Southern Pacific Railroad there were stretches of several hundred miles where water was unobtainable, or else was so alkaline as to be unfit for use. For a considerable time after the road was built it was considered necessary to haul with each train one or two large tank-cars carrying water in order to supplement the supply carried in the tender. Later the same railroad incurred considerable expense, after seeking the most expert geological advice obtainable on the probabilities of obtaining water by sinking Artesian wells, and thereby succeeded in locating water-stations approximately where they were desired by the operating conditions. In ordinary cases a comparatively simple treatment of the water with chemicals will so modify the injurious ingredients that they are virtually rendered harmless, so far as boiler use is concerned, although the water is still very far from being pure water. Of course the method of treatment depends entirely on the nature of the chemical present in the water. A treatment suitable for one kind of water would only render another kind of water still more harmful.

80. Methods of water purification.—One of the cheapest methods is to introduce a chemical directly into the tender-tanks. From here it passes to the boiler. Even this method is only suitable when the resulting precipitate will not cause a scale to form on the boiler-shell. At its best it requires frequent washing-out of the boiler. Such a method cannot be considered good practice, even though it is cheap.

When the impurities in the water consist chiefly of the carbonates of lime or magnesia which are held in solution, the treatment is very simple and inexpensive. These carbonates are only held in solution as long as the water is charged with carbonic-acid gas, as it always is under these conditions. If common lime is thrown into the water it unites with the free carbonic-acid gas and absorbs it. Since these carbonates are insoluble in water which is free from carbonic-acid gas, they are precipitated and the clear water may then be drawn off. The lime required for a water containing 40 grains of carbonates per gallon will cost less than one cent per thousand gallons. The cost of the labor may be more than this. A very few cents per thousand gallons will usually suffice for the cost of such purification. When the sulphate of magnesia is present the purifying is far more expensive, since it requires the use of sodium carbonate or "soda-ash" as a reagent. This is worth about one cent per pound, and the cost of the required amount for 1000 gallons will be about one cent for each eight grains of sulphate per gallon. Sometimes the water is so strongly impregnated that a very large amount of reagent is necessary, and the resultant water may become objectionable on account of "foaming."

A complete study of the precise chemical character of the water, together with the amount and cost of the necessary reagents, is the only wise method to pursue even *before* any source of supply is selected. Railroads have frequently found it wise to abandon sources of supply on which considerable money has already been spent, because it has been discovered that the water was selected without a proper appreciation of its disadvantages.

81. Pumping water.—The maintenance of water in the tanks is accomplished chiefly in one of four ways: (1) gravity, which is impossible or impracticable, except under peculiarly favorable conditions; (2) by windmills, which are too uncertain, unless an extra-large storage capacity is provided, which reduces the economy of the method; (3) by steam-engines; and (4) by gasoline-engines. The first two methods need hardly be discussed. Under especially favorable circumstances they have their advantages of economy of maintenance if not of first cost. The methods of direct engine-pumping are the only standard methods which are everywhere applicable. The development of gasoline-engines during the last few years has resulted in a very large increase in the use of engines of this type. The great advantages of the gasoline-engine type are due to the low cost of the gasoline, which is usually not more than 10 c. per gallon, and, secondly, the facility with which the engines are run, even by a very low grade of unskilled labor. The economy is even greater when the size of the plant is very small, since very small steam-engines will use as much as 15 or 20 pounds of coal per horse-power hour. Under similar conditions a gasoline-engine will use about one-tenth of a gallon. Some comparative estimates made by the Chicago & Alton Railroad at several places found that the cost of pumping (using coal) was anywhere from 1.4 to 3.4 times as great as the cost when using gasoline. Of course the absolute cost per thousand gallons depends very largely on the height to which the water must be raised, as well as on the size of the plant, but in round numbers it may be said that the cost of pumping water per thousand gallons by steam will vary from 4 to 10 c. per thousand gallons, while the cost using gasoline will vary from 1½ to 3 c.

82. Oil, tallow, and waste for locomotives.—These are quoted for the whole United States at an average price of .403 c. per train-mile, but it should of course be remembered that this figure is only an average figure which will be increased or diminished very largely in individual cases. Of course the cost is greater for heavier engines and heavier trains. The proportion of the item which should be assigned to the cars, which is perhaps not more than 50%, will probably vary nearly according to the number of cars per train. The cost per engine-mile varies with the size of the engine, and will be far cheaper per ton-mile for the heavier engines than for the lighter engines. The cost of this item for engines alone seems to vary from .15 c. per engine-mile for a very light passenger-engine up to .30 c. for a very heavy freight-engine. On the other hand, it was found from some figures compiled on the A. T. & S. F. R.R., that for two engines with loads behind them of 702 and 416 tons respectively, the cost of the oil and waste per mile was .28 and .24 c., but if we reduce these figures to the cost per thousand ton-miles, the cost was .40 and .58 c. respectively. Both wool-waste and cotton-waste are used, the wool-waste costing from 50 to 100 per cent more than the cotton-waste. The wool-waste is better for the cellar of a driving-box, since it is more elastic and will therefore stand up better against the under side of the axle. Cotton-waste is even better for the tops of journal-boxes, as it lies flatter and heavier, and therefore prevents the dust from getting on to the bearings. Tallow is also used for such purposes and is far cheaper than waste. This item is so very small that we may usually neglect any variations in the amount of it, except when we are considering the economics of heavy engines *vs.* light engines, and then the difference is worth considering.

Other supplies for locomotives include the tools, the sand, and all miscellaneous articles, such as metal polish, torpedoes, etc. Under the head of tools it includes oil-cans, lanterns, scoops, fire-bars, torches, etc. The cost of these items averages about .2 c. per train-mile, although the figure may vary 50% each way.

83. Comparative cost of various types of locomotives.—In Table XI are given the comparative costs of the various sizes of standard-gauge locomotives, the figures having been furnished through the courtesy of the Baldwin Locomotive Works. While these figures must be considered approximate, since the actual cost of a locomotive depends somewhat on the particular kinds of attachments which are used, the table has its value in indicating to an engineer the approximate cost of the desired equipment for a new road, and also shows the comparative costs of the various types of engines. The last column is particularly instructive, since it indicates the great economy of the Mogul type, and even more so of the Consolidation type, where the maximum of tractive power, rather than high speed, is the prime consideration. The table refers exclusively to simple locomotives. As a very approximate figure it may be stated that the cost of building any of these locomotives on the compound type will be approximately $2500 more than that of the corresponding simple type.

TABLE XI.—COMPARATIVE COST OF VARIOUS SIZES OF STANDARD-GAUGE SIMPLE LOCOMOTIVES. BALDWIN LOCOMOTIVE WORKS.

Cylinders.	Weight (net tons).		Cost, 1906.			
	Total.	On driving-wheels.	Total.	Engine.	Tender.	Per ton on driving-wheels.
AMERICAN TYPE.						
12″×22″	25	16	$6,800	$5,600	$1200	$425
13″×22″	30	19	7,200	5,950	1250	379
14″×22″	37.5	23.5	7,600	6,300	1300	323
15″×24″	42.5	27.5	8,100	6,700	1400	294
16″×24″	46	30	8,600	7,100	1500	287
17″×24″	50	33	9,200	7,650	1550	278
18″×24″	55	36	9,800	8,200	1600	272
MOGUL TYPE.						
16″×24″	45	39	$8,700	$7,400	$1300	$223
17″×24″	50	42.5	9,400	8,050	1350	221
18″×24″	53.5	45.5	10,000	8,550	1450	219
19″×26″	60	51	10,600	9,000	1600	208
CONSOLIDATION TYPE.						
20″×24″	69	61.5	$12,600	$11,000	$1600	$205
21″×26″	82.5	75	13,400	11,650	1750	179
22″×28″	95	85	15,000	13,250	1750	176

The Economics of Heavy Locomotives.

84. The problem stated.—A heavy locomotive costs considerably more than a light locomotive. A heavy locomotive costs more to operate, will burn more fuel, use up more water, lubricants, and other supplies. The heavier engine will cause more damage to the road-bed and will produce greater wear on the rails and ties. On the other hand, the wages paid to the enginemen, although somewhat greater on heavier locomotives, do not increase in proportion to the tonnage. The hauling capacity of the engine is far greater and the operating cost per ton-mile is far less. The introduction of air-brakes on all passenger-trains and on freight-trains to a sufficient extent to permit the engineer to handle the train, without the use of brakemen working hand-brakes, reduces the proportion of brakemen per car, or, in other words, increases the number of cars to one brakeman, and therefore decreases the cost per car or per ton-mile for train service. It is comparatively easy to demonstrate that the cost per ton-mile of handling the trains by means of heavy engines is less than the cost when using light engines. The precise determination of such economy is far more difficult, and must of course be considered to some extent uncertain. It is not a very difficult matter on any one road to determine the relative cost of operating two types of engines, one of which can haul 60 to 70% or even 100% more cars than another. But even after such calculations are made the results have only a general value, since they apply only to those two types of engines. Of course such comparative figures will have their value to the railroad manager who is considering the policy of renewing or substituting for his old light-weight locomotives a far heavier type of locomotive, and who wishes to justify the additional expenditure for the heavier locomotives by a demonstration of the economy that would be obtained by using it.

Perhaps the most simple method of making the calculation is to consider the value of the substitution on the basis of the number of trains that would be thereby saved in handling a given amount of traffic. It may readily be appreciated that the gross amount received by a railroad company for handling a certain gross tonnage of freight is a perfectly definite figure, which is neither increased nor diminished whether it is handled in four, six, or eight train-loads. If the manager can demonstrate that by the substitution of heavier locomotives a certain gross tonnage of freight can be handled in one or two less trains than would be required by the lighter locomotives, it is only necessary to compute the saving by running a less number of heavier trains, and then he has a basis on which to determine the justification of the added cost of his heavier locomotives.

85. Economy effected by handling a given traffic with one less train.—The general method adopted in this connection will be to consider the percentages of the various items of cost of a train-mile as given in Chapter VI, and to estimate the effect of the special circumstances of the problem on each one of these subitems. If the relative power of the two types of locomotives considered is such that the heavier locomotives can haul in three trains as many loaded cars as those of the lighter type would handle in four trains, or if the heavier engines handle in four trains as many cars as would require five trains with lighter engines, then the use of the heavier engines will save one train in four or one train in five, as the case may be. We will therefore compute the added cost of running the extra train. We may also consider this cost to be the same as the saving by avoiding the extra train, but, since the number of cars remains the same, we may consider that the total added cost is the cost of running say four engines instead of three. Of course, this does *not* mean the cost of running the additional engine "light." In the case here considered the gross tonnage of freight to be handled is assumed to be constant. We will therefore assume that the total number of cars used in handling the freight is identical. We may therefore assume that the effect of these cars on the wear and tear of the track

(Item 1) will be constant. It has been estimated that locomotives are responsible for approximately 50% of the general track-wear, on account of the greater concentration of loads on the driving-wheels. In recent years the wheel-loads of the heaviest freight-cars are as great as, or greater than, the driving-wheel loads of a few years ago, but the driving-wheel loads have also increased, although not in as great proportion. Although the disparity between driving-wheel loads and car-wheel loads is not now as great as it was twenty years ago, it is still sufficiently great, so that we may assume that 50% of the damage is the result of the wear due to locomotives.

86. Maintenance of way.—The analysis of the subitems of Item 1, repairs of roadway, in Chapter VI, shows that a very large proportion of them are wholly independent of the tonnage or exact number of trains. It is safe to say that not more than 25% of the cost of track-labor will be influenced by the addition or reduction of a single train. If, therefore, we consider the engine to be responsible for 50% of the damage, we can add 50% of 25%, or 12½%, for the additional cost due to the extra engine. The renewal of rails and the renewal of ties will probably vary much more nearly in proportion to the number of trains. If we were to consider that repairs of roadway were strictly according to the tonnage, then there would be but little difference between the two systems of running four trains or three, since if the tractive powers of the engines were as 3 to 4, the weights of the engines would be approximately in the same ratio; but experience shows that the expenses of repairs of roadway have a singular uniformity per train-mile, regardless of whether the traffic is light or heavy. In the face of this, it is impossible to say that, since the gross tonnage would be nearly the same by both systems, we should consider that track repairs would likewise be the same for either system of operating.

It is probably conservative to say that the running of 4 trains instead of 3 will add 50% of the average cost of a train-mile to these two items.

The repairs and renewals of bridges and culverts (Item 4) will only be affected to the extent that the repairs of truss-bridges will evidently depend somewhat on the tonnage. The proportion of truss-bridges and of stone arches would evidently have an effect on this item, but it is so small that the uncertainty is of but little importance. On the one hand, we might say that the deterioration of truss-bridges would be increased by the heavier gross train-load, and especially by the heavier engines; but, on the other hand, as in the above item, the repairs have some relation to the number of trains. We will therefore consider the item as balanced, and the net effect zero. The other items of maintenance of way can hardly be said to be affected by the number of trains, except a possible addition of an insignificant amount to the item for buildings, due to the care of the extra engine in the engine-house.

87. Maintenance of equipment.—Under the items of maintenance of equipment, the repairs of locomotives (Item 12) is the first important item to consider. The real question regarding this item is, Will the cost of engine repairs on four light engines be greater than on the three heavier engines which will do the same work? If we apply the rule that the cost of engine repairs equals 1 c. per ton of average tractive force per mile, plus 1 c. per engine-mile, we will find, since the sum of the tons of tractive force required to haul the total tonnage of cars must be considered the same, that part of the item will balance. The other part of the item of repairs will vary according to the number of engine-miles; but the total item consists partly of the cost of renewals, and, since we may assume that the cost of the four light engines is nearly the same as that of three heavier engines, we may consider that the part of the item which has to do with renewals balances. Evidently no one figure will be a correct answer for every case, but the method may be indicated as follows: Assume that we are comparing two types of engines, one of them having a tractive force of 15 tons and the other a tractive force of 20 tons. Then four of the lighter engines will be required to haul the same load which can be hauled by three of the heavier engines. Assume that an average of 50% of the maximum tractive force is utilized for the entire trip. Then according to the rule the cost of repairs for the three heavy engines would be $(.50\times20)3+3$ and for the light engines $(.50\times15)4+4$, or 33 c. and 34 c. per mile respectively. It should be noted that, under the assumptions made, the largest part of the above items are identical for the two cases, and that the difference is very small. In fact, the difference is probably smaller than the probable error of the method of computation, and therefore we can probably say that, so far as Item 12 is concerned, the *additional* cost for engine repairs of using one additional locomotive to do the work, or the saving accomplished by using the heavier locomotive, will be practically zero.

When we consider the repairs to the rolling-stock, we have an actual advantage in using light engines, since the average draw-bar pulls with the lighter train and the impact due to sudden stoppage is less, and, although some of the items of repairs will evidently be unaffected, none of them will be increased. The amount which they can be decreased is almost non-computable, since it depends on circumstances which in general cannot be foreseen. If the particular question involved concerns only the use of freight-locomotives, then we must ignore Item 13, the repairs of passenger-cars. If we analyze the cost of repairs of freight-cars, and consider that a very large proportion of them are due to causes which have nothing to do with this question, we can see the justification of the estimate which has been made, that the cost of repairs of freight-cars may be *reduced* 10% by the adoption of a greater number of trains to handle a given traffic. Even though this estimate may be considered as guesswork, it is quite evident that its error cannot be a very large percentage of itself, and it is quite certain that the error is only a very small percentage of the total quantity which we are trying to compute. Items 15 to 19 are unaffected by this question.

88. Conducting transportation.—Item 20, superintendence, which includes only the salaries of higher transportation officials, may be considered to be unaffected. Item 21, the wages of enginemen, although they vary somewhat with the tonnage of the locomotives, do not vary in strict proportion to it. Some schedules of wages pay no attention to the weights of locomotives, but only consider the class of service, whether passenger service, through-freight, or local freight. In such cases the amount paid in wages would be strictly according to the number of engines. In other cases there is an addition of 5 to 10% paid for handling the heavier engines. Assuming an average of 8% increase, we would have for four light engines 400% and for three heavy engines 324%, or an addition of 76% of the average wages for one engine, as the result of using the additional engine. Of course this item will vary with each particular case. The relative cost of fuel consumption with the heavier engines depends very largely on the particular engines compared. It is not unknown that a considerably heavier engine of one type may actually burn less fuel than a lighter engine of another type and make. When we consider the very large amount of fuel which goes to waste by radiation, the amount which is consumed when an engine is doing very little or no work, as when it is running on a level or on a down grade, and the proportion which is consumed in various other ways, as has already been described, it may readily be seen that only a small proportion of the fuel used may be considered as proportionate to its tonnage or proportionate to the weight on the drivers. The late A. M. Wellington considered that 75% of the fuel used would be unaffected by the weight of the engine, and that only the remaining 25% would be affected according to the tonnage. We might therefore express the amount of fuel used by four light engines as

$$4\times75\%+4\times25\%=400\%.$$

The cost of operating three heavy engines may be expressed as

$$3\times75\%+3(\tfrac{4}{3}\times25\%)=325\%.$$

Therefore the *added* cost of fuel for the one lighter engine would be 75% of the average figure for one. We will consider that the other engine-supplies are affected similarly. Items 26 to 32 may be considered as being strictly proportional to the number of trains, and therefore that the addition of an extra train will add 100%. We will consider the item of car-mileage as being unaffected. Items 34 to 37, damages, etc., will be considered as being affected 100%. The miscellaneous items, 38 to 44, will in general be unaffected. Items 45 and 46 will probably be affected somewhat, although it is impossible to say how much. The items fortunately are so small that it will make but little difference what percentage is chosen. It will probably lead to no material error to say that these items will be affected 50%. The general expenses, Items 47 to 53, will evidently be unaffected. If we multiply the normal average percentages, as given in Table IX, for the last ten years by the percentages which have been estimated for each item, the summation of these products will be the percentage of the average cost of a train-mile, which will be an estimate of the cost of the assumed condition. If we multiply this by the average actual cost of a train-mile

TABLE XII.—ADDITIONAL COST OF OPERATING A GIVEN FREIGHT TONNAGE WITH FOUR LIGHT ENGINES INSTEAD OF THREE HEAVIER ENGINES.

No.	Item (abbreviated).	Normal average, per cent.	Per cent affected.	Cost per cent.
1	Roadway.	10.767	12.5	1.346
2	Rails.	1.422	50	.711
3	Ties.	2.948	50	1.474
4	Bridges and culverts.	2.461	0	0.
5–10	Buildings, etc.	3.436	0.	0.
	Maintenance of way.	21.034	. . . . . .	3.531
11	Superintendence.	.617	0.	0.
12	Repairs of locomotives. . . .	6.538	0.	0.
13	“ “ passenger-cars. . .	2.174	0.	0.
14	“ “ freight-cars.	7.160	−10	−.716
15–19	Miscellaneous.	1.535	0.	0.
	Maintenance of equipment.	18.024	. . . . . .	−.716
20	Superintendence.	1.757	0.	0.
21	Enginemen.	9.607	76	7.301
22–25	Fuel, etc.	11.542	75	8.656
26–32	Train-service, etc.	23.149	100.	23.149
33	Car-mileage.	1.829	0.	0.
34–37	Damages, etc.	2.288	100.	2.288
38–44	Miscellaneous.	5.307	0.	0.
45–46	Stationery, etc.	1.157	50.	.578
	Conducting transportation	56.636	. . . . . .	41.972
47–53	General expenses.	4.305	0.	0.
		100.000	. . . . . .	44.787

we will have an estimate of the cost of one mile of this sort of operation. It is a question whether we should take the average figures for the last ten years, or the average figure for the last year alone, or, perhaps, even a still higher figure. As is indicated by Tables VII and IX and Fig. 6, the average cost per train-mile seems to be steadily increasing, while certain of the percentages of the items of cost seem to be *regularly* increasing (or diminishing) instead of merely fluctuating. On this account the *averages* for the past ten years will probably be incorrect as an estimate for immediate future costs. These percentages have been combined in Table XII, page 135. If we assume that the average cost of a train-mile is \$1.30, then the operating value of saving the use of the additional engine equals 45% of \$1.30 or 58 c. There is, however, one additional item to be considered. Although Item 12 includes repairs and *renewals* of locomotives, it does not include the addition, if any, for the capital cost of the extra locomotive. Perhaps this extra cost may be zero. If we consider that the cost of locomotives is roughly proportional to their tonnage, and that, with locomotives of the same type, the tractive force is nearly proportional to their tonnage, then the four locomotives would cost no more than the three heavier locomotives of equal power. But if the four locomotives cost somewhat more (as is probable), then the extra cost, say \$2000, divided by the mileage life of the locomotive, say 800,000 miles, would require 0.25 c. to be charged to the above cost per mile. In this case the addition is almost too small for consideration, but in other cases it should not be neglected.

89. Numerical illustration.—Assume that the general manager of a road is considering the justification of employing heavier locomotives to handle a given tonnage. Let us assume that he can depend on a daily traffic which will fill 120 cars per day, having an average gross weight of 70 tons per car. This gives a total weight behind the tender of 8400 tons. A locomotive with a tractive force of 30,000 pounds would probably have a total weight of about 140 tons. When the tractive resistance on the level is six pounds per ton, the total grade resistance on a grade of 35 feet per mile is about 19.5 pounds per ton. If we have a tractive force of 30,000 pounds this would permit the hauling of trains with a gross load of 1540 tons. Subtracting the weight of the engine and tender, about 140 tons, we would have 1400 tons as the permissible weight of cars behind one engine. This will permit the total tonnage to be handled in six trains with this type of engine. To handle this same tonnage in five trains instead of six will require a load of 1680 tons behind each engine. Assume that the heavier engines have the same ratio of tractive power to total weight, which is about 10.7%. On this basis, letting W equal the weight of the locomotive in tons, we may say that $(1680+W)\ 19.5 = 2000W \times .107$. Solving this for W, we find that the weight of the locomotive would be 168.4 tons, or about 337,800 pounds. We would then have as the cost of handling that traffic in five trains, five times $1.30, or $6.50, for each mile of the road. Handling the traffic in six lighter trains with lighter engines will cost a somewhat less price per train-mile, which may be expressed by the figure of five times $1.30 for five trains and 58 c. for the sixth train, which will make $7.08 for the six trains, or $1.18 per mile for the average of the six trains, rather than $1.30 per mile for the five heavier trains. The net difference, however, is the 58 c. per mile of road per day. If the division to which this applies is 100 miles long, it means an added expenditure of $58 per day, or about $20,000 per year.

The student is especially cautioned that the above demonstration should be considered as an outline of a method of investigation, rather than a computation of values to be used. The separate items should be carefully investigated in applying this method to any particular case.

CHAPTER VIII.

ECONOMICS OF CAR CONSTRUCTION.

90. A very large part of the economy which has been accomplished in railroad transportation during recent years has been due to improvements in the construction of freight-cars. In this chapter we must ignore altogether the improvements of passenger-cars, since development in passenger-car construction has followed the lines of increase in weight and in the allowable luxury of travel, rather than along economical lines. Improvements have likewise been made to increase the safety of train operations, such as improvements in couplers, air-brakes, etc. But the improvements in car construction which have tended toward economy in railroad operation have been practically confined to freight-cars. These improvements consist chiefly in increasing the strength of thecar and its capacity, without proportionately increasing its deadweight. This reduction in the ratio of dead load to live load has been one of the most potent causes in the reduction of freight-charges. But these heavier cars have absolutely required improved couplers, which are not only more capable of handling the heavier loads but are less subject to deterioration and breakage. Another very potent means of economy in the handling of freight-trains is the application of air-brakes to freight-cars. In fact the very heavy trains now operated on some roads could not be safely handled, especially at such speeds as are used, without the adoption of all these improvements.

91. Weight of cars.—The statistics furnished by the Interstate Commerce Commission give a very accurate idea of the capacity of the freight-cars used in the United States. The total number reported in 1904 was nearly 1,700,000, with an aggregate capacity of over 50,000,000 tons. The average capacity is thus about 30 tons, which is a very great increase over the corresponding figures of a few years ago. The report showed in the lightest class 4812 cars with an average capacity of 6 tons, nearly half of them being coal-cars. At the heavy end of the list were two cars, each with a capacity of 150,000 pounds. About 42% of the total number have the same capacity as the average (30 tons), and about 21% have a capacity of 40 tons. The increase in the average capacity during a single year was about one ton. This statement alone is a significant commentary on the economy which has been universally demonstrated in the use of cars of large capacity.

92. Ratio of live load to dead load.—A. M. Wellington, writing in 1885, gave as the weight and capacity of a "new standard box-car" 24,800 and 50,000 pounds respectively. The corresponding figures for the "old" standard cars were 20,900 and 30,000 respectively. The "new standard cars," therefore, had a carrying capacity of little over twice their dead-weight, while the carrying capacity of the old standard was about 144% of the dead-weight. Since then, cars with a carrying capacity of 60,000, 80,000 and even 100,000 pounds have become not only common, but almost standard. As an average figure, we may say that the car with a carrying capacity of 100,000 pounds will weigh about 38,500 pounds. The ratio of live load to dead load has been increased from 144% to 260%. When freight-cars are used to the limit of their capacity (at least in the direction of heaviest traffic), they are frequently loaded with a live load that is about 10% greater than their rated capacity. It is thus seen that the heaviest cars can be, and frequently are, loaded with a load which is about 2.86 times the dead load. There is, therefore, no exaggeration in the subsequent calculations on tonnage ratings to consider that a train of fully loaded cars has a live load which weighs twice the dead load. In fact, such a statement is conservative, considering what may be done and sometimes is done.

93. Economics of high-capacity cars.—The following line of argument, showing the economy in heavy cars, is condensed from an elaborate presentation of the subject by Mr. Rodney Hitt, which was published in the Railroad Gazette, May 19, 1905. The advantages are briefly stated as follows:

1. The smaller number of cars which are required to transport a given amount of freight. The actual investment in equipment is smaller, since the increase in cost is not proportionate to the increase in capacity. There is less work for the car-service department; the empty car movement in the direction of least traffic is decreased.

2. The number of cars, and even the number of trains, required to handle a given traffic is very materially decreased. Economy in this direction might be computed in a manner very similar to the computation of the economy in using heavier locomotives as given in Chapter VII. This economy, of course, involves a saving in the wages of train- and engine-crews, an economy which is independent of the number of tons hauled, and which depends chiefly on the number of trains required to handle the traffic.

3. There is a saving in the cost of car repairs—per ton capacity, if not per car. The amount of this saving is not easy to compute, and under some circumstances it is *apparently* negative. The high capacity cars are necessarily built with steel frames and are sometimes built entirely

of steel. Such cars have established an enviable record by their immunity from material damage during train-wrecks, when lighter wooden cars, caught in the same wreck, have been utterly destroyed. Although the early designs of high-capacity cars were not properly designed with respect to draft-gear, wheels, etc., and therefore their records of repair charges were abnormally large, improvements in design have resulted in a reduction of such charges, even below the average figures for the lighter rolling-stock. It has been found that the repair charges on lighter rolling-stock have been materially increased when such cars have been used in the same trains with the heavier steel cars, since the effect of a collision or serious bumping during careless switching almost invariably results in a crushing of the light wooden car, although the heavier steel car usually suffers no damage. The cars of latest design have shown a very considerable economy in the cost of repairs per ton-mile.

4. There is a reduction in the frictional and atmospheric resistance per ton. The frictional resistance per ton decreases with the axle-load. The atmospheric resistance, depends almost entirely on the number of the cars. The lighter and heavier cars are so nearly of the same size that the very slight increase in atmospheric resistance, which is due to an increase in size, is of no importance in this case. "An engine which can haul 1000 tons in 90 cars can haul 1250 tons in 50 cars at 8 miles per hour, and at higher speeds the difference is still greater."

5. There is a saving in track-room in yards and terminals. An 80,000-pound car occupies but little more track-room than a 40,000-pound car, while it permits twice as much freight to be loaded and unloaded in the same time. This consideration is of special importance in the congested terminals of the trunk lines at tide-water, where land is so very valuable. The recent difficulties of

railroads in clearing some of their freight-yards would have been very largely augmented if the cars had an average capacity of only 10 or 15 tons rather than 30.

6. There is a saving in switching charges per ton of revenue load. The cost of moving a car through a division or terminal yard varies from 20 to 65 c., as was shown in a recent report from one of the large railroad systems. If a car is passed through four yards on one trip, the cost of switching, etc., may be as high as $2. For a 50-ton car this is at the rate of 4 c. per ton, while for a 20-ton car it is 10 c. per ton, which is an appreciable difference.

94. Use of air or train-brakes.—It is needless, in this period of railroad history, to argue the value of air-brakes in the operation of trains. According to the report of the Interstate Commerce Commission for the year 1904, out of nearly 40,000 passenger-cars all but 297 were fitted with train-brakes. It is conceivable that even these 297 are merely old cars, which are wearing out their last years of service on lines which are being operated so cheaply that even such an improvement is financially impossible.

Of nearly 1,700,000 freight-cars all but 258,000 (a little over 15%) have been equipped with train-brakes. Even this proportion of cars which are not equipped with train-brakes is far smaller than it was a few years ago. In 1889 less than 12% of the total number of cars and locomotives were equipped with train-brakes. In fifteen years the proportion has been increased from 12 to over 84%. It is probably safe to say that no new regular equipment is now being built without train-brakes.

The operation of passenger-trains at high speed, and the operation of very heavy freight-trains at almost any speed, but especially at high speed, would be absolutely unsafe without the use of air-brakes. Their use is now so universal and their advantages so well recognized that no further comment is necessary.

95. Use of automatic couplers.—The use of automatic couplers to replace the old-fashioned link-and-pin coupler was ordered by Congress on all cars used in interstate traffic. In 1889 the percentage of equipments fitted with automatic couplers was less than 8%. In 1904 it had increased to nearly 99%. As in the case of the air-brakes it is needless to point out the advantages. The old link-and-pin coupler was not only inadequate for the heavy rolling-stock as used at present, but was always a fruitful source of injuries and death to railroad employees, chiefly brakemen. With the demand for something to replace the old link-and-pin coupler, a multitude of inventors came forward with various plans. The Patent Office was besieged with claims for patents on every conceivable method. The interchange of freight-cars among various roads and the combinations of such cars into trains imperatively demanded that some standard should be adopted, so that whatever the details of the coupler all couplers should be capable of being used with each other. The Master Car-builders' Association therefore adopted a standard outline. All the automatic couplers now in use have the same essential outline as is shown in Fig. 7. The variations of the different designs have to do entirely with the details of their method of operation or the manner of their fastening to the car-body.

96. Draft-gear.—The demand for heavier locomotives and heavier cars has entailed with it the requirement that the draft-gear of cars must be improved. The frictional resistance which must be overcome in starting a train, as well as the inertia, is very great. But the figures which have been determined experimentally as the starting resistance are much less than they would be if it were not for the slack which always exists to a greater or less extent between cars. In the old days of link-couplers, especially when the links were fastened to a coupler which was *rigidly* attached to the car-body without the intervention of spring draft-gear, although the links made some slack, the inevitable result was a jerk on the coupler which would frequently tear it loose from the car-body, even if the car-frame was not badly wrenched or torn apart. The adoption of close couplers removed all the slack which had formerly existed in the links, and was only made practicable by the use of spring draft-gear, which permits a yielding either in compression or tension.

97. **Spring draft-gear.**—In Fig. 7 is shown an illustration of a spring draft-gear and the method of its attachment to the car-frame. This is the recommended practice as adopted by the Master Car-builders' Association at their convention in 1896. By vote of the association it was decided, as their opinion of standard practice, that the draft-spring should be $6\frac{1}{4}''$ in diameter, $8''$ long, and with a permissible motion of $2\frac{1}{8}''$. The capacity of the spring was placed at 19,000 pounds. These figures are given since they indicate the standard in accordance with which a large proportion of the freight-cars now in existence were built; but, as shown later, they are far from representing the present standard practice for future construction. It should be noted that the essential features of such a coupler consist of the yoke *N* which passes around the two followers *BB* which are separated by the heavy spiral springs *R*; the followers *BB* extend out beyond the yoke, where they press against the shoulders which are fastened into place by four heavy bolts. During compression the front follower presses against the spring which transmits the pressure to the rear follower, which, in turn, transmits the pressure to the shoulders and the car-body. During tension the yoke *N* is drawn forward, which draws forward the rear follower which transmits its pressure through the spring to the front follower, which, by pressing against these shoulders, draws the car

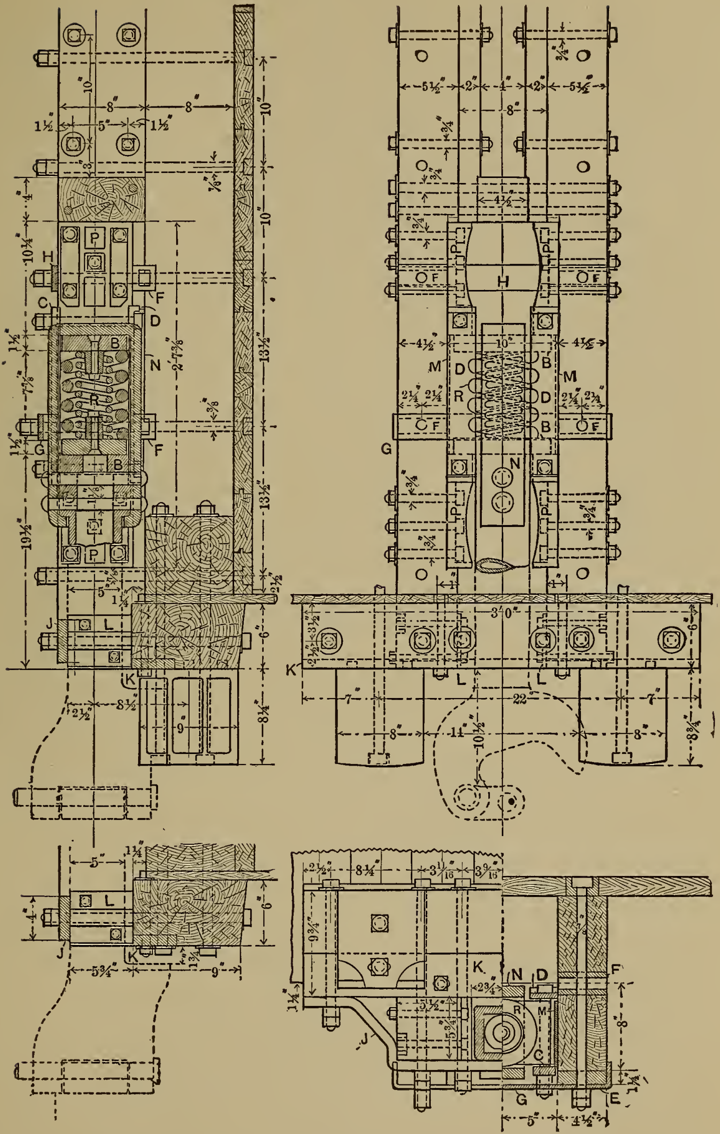


FIG. 7.—Spring Coupler, showing method of attachment as recommended by Master Car Builders' Association in 1896.

forward. In either case the spring is compressed. Fig. 7 also gives in outline form the standard dimensions and shape as required for an M.C.B. coupler. No details are given, as they are left to the individual designer of the coupler. Any couplers which have those same outline dimensions may be operated with any other coupler with the same standard dimensions, regardless of their precise design. Spring-couplers are used on a very large majority of the cars now in service, and they answer their purpose as long as the total weight of the cars with their loads is not excessive, and provided that the handling of cars in freight-yards is done with care. The enormous freight business handled by railroads during recent years has resulted in a considerable increase in the cost of freight-car repairs, which has been due very largely to the fact that freight-yard men have been required and urged to do their work as quickly as possible. This has resulted in a far higher average velocity in freight-yard movements. The invariable consequence is a jerking of the cars when they are pulled forward and a severe compression of the cars when they run together. Considering that the effect of impact increases as the square of the velocity, an increase in the velocity of yard movement from one mile per hour to two or three miles per hour will mean that the destructive impact will be from four to nine times as great. The adoption of very heavy steel cars has had the incidental disadvantage of increasing the cost of repairs of the lighter wooden cars, since the heavy cars, with their greater weight and especially with the greater velocity of freight-yard movement, which is now so common, will crush lighter cars between them. The inevitable result has been that with the continued growth of weight of rolling-stock even the spring principle became inadequate. It became necessary to introduce some device which would be better capable of absorbing the very great shocks due to compression and also the jerks due to the sudden starting of a very heavy and powerful locomotive. This was accomplished by means of "friction" draft-gear. The committee on draft-rigging of the Western Railway Club reported to the club in May, 1902, on some tests of draft-rigging as follows:

"From the general results of the tests, it is believed that the tensile strains in draft-gears with careful handling will frequently reach 50,000 pounds, with ordinary handling 80,000 pounds, and with decidedly rough handling fully 100,000 pounds, while the buffing strains can be placed at 100,000, 150,000, and from 200,000 to 300,000 pounds respectively. In extreme cases the buffing strains will go considerably above the last-named figure. We think the figures show the necessity of something better and more effective than the spring draft-gear as commonly used. It would be reasonable, in view of the above figures, to require draft-gears and underframes to be capable of withstanding tensile strains of 150,000 pounds, and buffing strains of 500,000 pounds, and it is evident that the present spring resistance is inadequate. Whatever one may think of the details of the various friction draft-gears, it must be evident that in the character and amount of resistance they are superior to the spring-gears."

98. **Friction draft-gear.**—The principle underlying friction draft-gear is that of a device which shall harmlessly transform into heat the excessive energy produced by the shocks of the operation of trains. The frictional draft-gear constructed by the Westinghouse Air-brake will be here briefly described. This gear employs springs which have sufficient stiffness to act as ordinary spring-couplers for the ordinary pushing and pulling of train operations. Sections of the gear are shown in Figs. 8 and 9, while the method of its application to the framing of a car of the pressed steel type is shown in Fig. 10, *a* and *b*. When

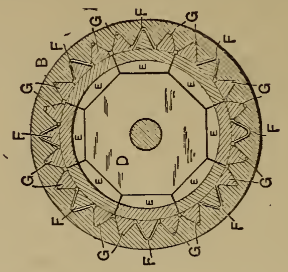


FIG. 9.—Cross-section.

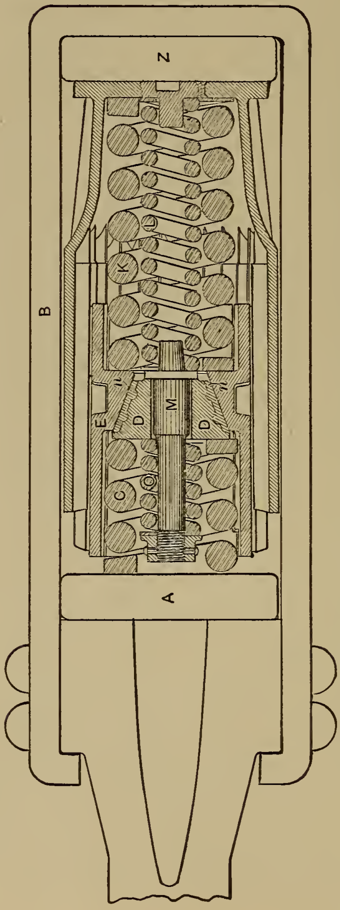


FIG. 8.—Longitudinal section of Westinghouse friction draft-gear.

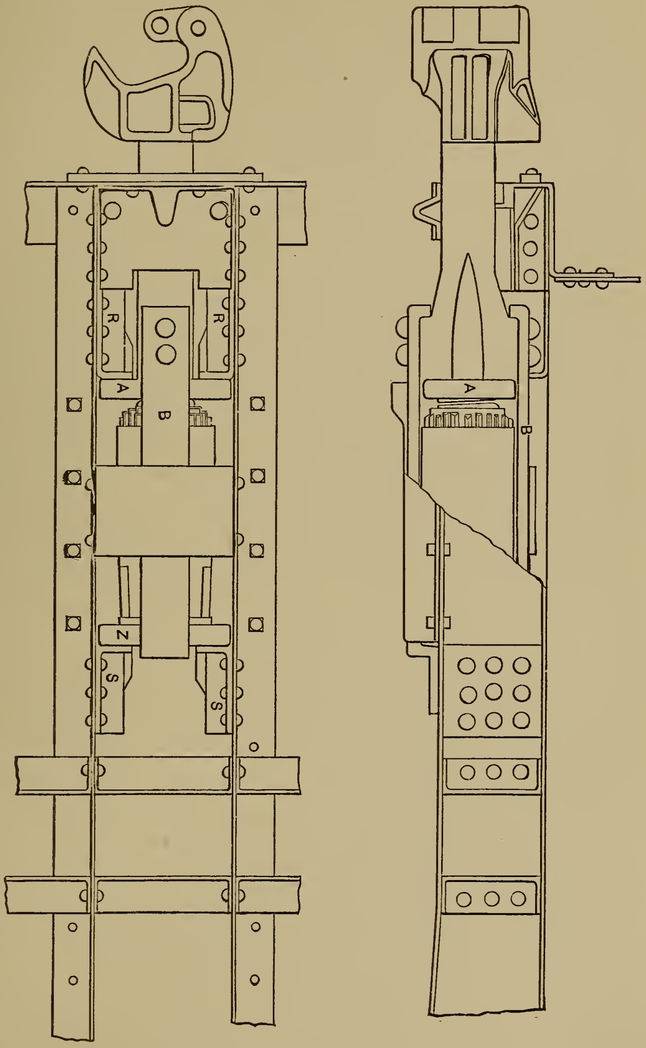


Fig. 10.—Application of the Westinghouse friction draft-gear to freight-cars of the pressed-steel type.

the draft-gear is in tension the coupler, which is rigidly attached to *B*, is drawn to the left, drawing the follower *Z* with it. Compression is then exerted through the gear mechanism to the follower *A* which, being restrained by the shoulders *RR*, against which it presses, causes the gear to absorb the compression. The coil-spring *C* forces the eight wedges *n* against the eight corresponding segments *E*. The great compression of these surfaces against the outer shell produces a friction which retards the compression of the gear. The total possible movement of the gear, as determined by an official test, was 2.42 inches, when the maximum stress was 180,000 pounds. The work done in producing this stress amounted to 18,399 foot-pounds. Of this total energy 16,666 foot-pounds, or over 90%, represents the amount of energy absorbed and dissipated as heat by the frictional gear. The remaining 10% is given back by the recoil. The main release spring *K* is used for returning the segments and friction strips to their normal position after the force to close them has been removed. It also gives additional capacity to the entire mechanism. The auxiliary spring *L* releases the wedge *D*, while the release pin *M* releases the pressure of the auxiliary spring *L* against the wedge during frictional operation. If we omit from the above design the frictional features and consider only the two followers *A* and *Z*, separated by the springs *C* and *K*, acting as one spring, we have the essential elements of a spring draft-gear. In fact this gear acts exactly like a spring draft-gear for all ordinary service, the frictional device only acting during severe tension and compression.

CHAPTER IX.

TRACK ECONOMICS.

In this chapter will be discussed some of the items of the cost of track construction and maintenance, which are so large and important that they should be studied with great care, in order to discover any possible economies. Chief among these items are the costs of rails and ties. A very brief study of the subject will show that variations in the weight and character of the rolling-stock, the rate of grade, the amount and sharpness of curvature, etc., will modify the expenditure which may, *with the best economy,* be made on these two items.

Rails.

99. Rail wear — theoretical. — Definite information on this subject is very difficult to obtain. If rails were only renewed when a certain proportion of their total weight had been worn away—say one-quarter of the head or about 10% of the total weight—then it would be a comparatively simple matter to estimate the effect of alinement on rail wear. But it frequently, if not generally, happens that rails on tangents are removed, not on account of wear on the head, but on account of failure at the joints.

When the steel of a rail is comparatively soft and ductile, the effect of concentrated wheel-pressure is to cause an actual flow of the metal, so that it will spread outside of its original outline, as is shown in the figure. The burr on the inside of the head will generally be worn off by the occasional pressure of a wheel-flange against the rail. The top of the rail will be worn with a slight slope to the inside, which corresponds somewhat with the coning of the wheels.

Fig. 11 shows the usual outline of a worn rail on the outside of curves. The wear is largely on the inner side of the head, the side of the head being practically gone before the top of the rail is much worn. The inside rail of a curve will wear to about the same form as a rail on a tangent, as shown in Fig.12, but the wear is much faster.

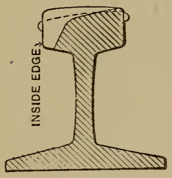


FIG. 11.

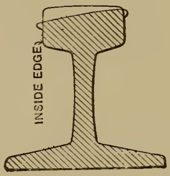


FIG. 12.

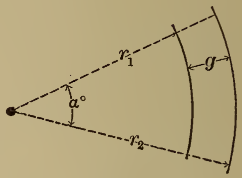


FIG. 13.

Rail wear on curves is due chiefly to two causes: slipping due to unequal length of the rails and grinding of the side of the head by the wheel-flanges.

(*a*) *Longitudinal slipping.* When a pair of wheels which are not rigidly attached to their axle run around a curve (see Fig. 13), the outer wheel must roll a distance $\frac{2\pi\alpha^\circ}{360^\circ}r_2$ and the inner wheel will roll a distance of $\frac{2\pi\alpha^\circ}{360^\circ}r_1$. The difference equals $\frac{2\pi\alpha^\circ}{360^\circ}(r_2-r_1)$ or $\frac{2\pi\alpha^\circ}{360_\circ}g$. This shows that when the wheels are *fixed* for any one gauge (g), the slipping is proportional to the number of degrees of central angle, equals $c\alpha^\circ$, and is *independent of the radius.* This slipping must be accomplished by the inner wheel slipping forward or the outer wheel slipping backward, or by a combination of the two which will give the same total amount of slipping. It is quite probable that the most of the slipping occurs on the inner rail, and that this accounts for the great excess of rail wear on the inner rail of a curve over that on a tangent.

(*b*) *Lateral slipping.* The two (or three) axles of car-trucks and the two or more driving-axles of a locomotive are always set *exactly* parallel to each other. This is done so that each pair of wheels shall mutually guide the other and maintain each axle approximately perpendicular to the rails. If the two axles of a truck are not exactly parallel, the truck has a constant tendency to run to one side, producing additional track resistance, rail wear, and wheel-flange wear. When two pairs of wheels with parallel axles are on a curve, the planes of at least one pair of wheels must make an angle with the tangent to the rails. When the radius of the curve is very short compared with the length of the wheel-base (as generally occurs at the street-corners of street-railways), then both axles will make angles with the normals to the curve, as shown in Fig. 14. The normal case for ordinary railroad work with easy curvature is that shown in Fig. 15, in which the *rear* axle stands nearly or quite normal to the curve, while the front axle makes an angle $\alpha°$ with the normal, and the plane of the wheel makes an angle of $\alpha°$ with the rail. The relative position of the outer front wheel and the rail is shown more clearly, although in an exaggerated way, in Fig. 16. The wheel *tends* to roll from *a* to *b*. Therefore, in moving along the track from *a* to *c*, it rolls

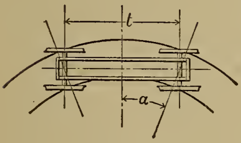


FIG. 14.

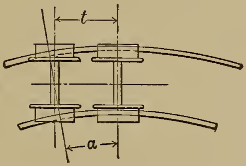


FIG. 15.

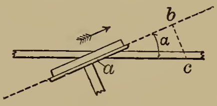


FIG. 16.

the distance ab and slides laterally the distance bc, which equals $ac \sin \alpha$. In the usual case (Fig. 15) $\sin \alpha = t \div r$. When $t = 5'$ and $r = 5730'$, the radius of a 1° curve, $\alpha = 0° \ 03'$. For the usual radii of railroad curves α will vary almost exactly with the degree of the curve. For example, on a 6° curve, using a 5-foot wheel-base, $\alpha = 0° \ 18'$ and $\sin \alpha = .0052$. For each 100 feet traveled along a 6° curve, the lateral slip of the front wheels is 0.52 foot, or about $6\frac{1}{4}$ inches. If the rear axle remains radial there is no lateral slipping of the rear wheels.

It can readily be seen that when the angle α is large, the wheel-flange continually grinds the side of the head of the rail. The larger the angle the more direct and destructive is the grinding action.

100. Rail wear—statistics.—It is very difficult to obtain reliable figures regarding rail wear and especially of the rail wear on curves. Such figures as are obtainable are almost hopelessly contradictory. The author has corresponded with the Chief Engineers or Engineers of Maintenance of Way of several prominent railroads in the hope of collecting such data. Very few satisfactory answers were obtainable. Usually the answers gave merely the average total life of rails on tangents and on various curves. It should not be forgotten that almost the only value of the figures quoted below lies in the statement of the *relative* life on the various curves of any one division of a road where the rails are of the same kind and are subject to exactly the same train-loads. One such statement is given by Mr. W. B. Storey, Jr., Chief Engr. of the A. T. & S. F. Rwy. The statement gives the approximate times of rail removal of 75-lb. A. S. C. E. rails on mountain curves of that road, on which the freight-trains are hauled by "Santa Fé" engines, which are decapods with trailing wheels, and have a very long wheel-base.

TABLE XIII.—LIFE (IN MONTHS) OF RAILS ON MOUNTAIN CURVES—A. T. & S. F. RWY.

	10°	8°	6°	5°	4°	3°
Outer rail.	9 mo.	15	24	40	56	6 to 8 yrs.
Inner rail.	18 mo.	24	48	60	72	. . . .

The relative life of these rails is better appreciated by a consideration of the curves of Fig. 17.

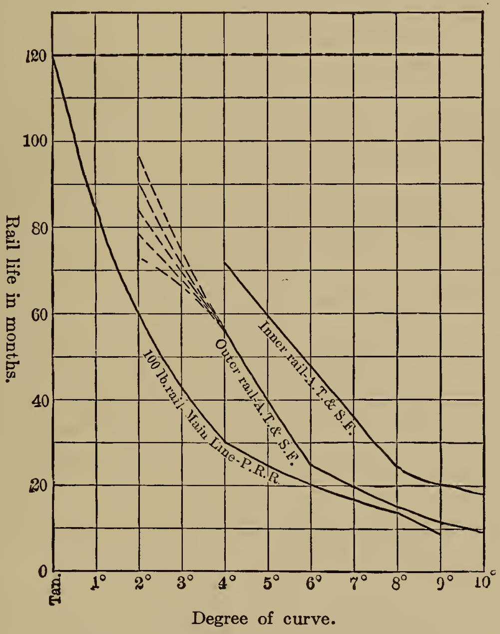


FIG. 17.—Total rail life in months.

A similar statement was furnished by Mr. A. C. Shand, Chief Engr. of the P. R.R. This statement does not differentiate between the wear on the outer and inner rails. It gives the average life of 100 rails which are subject to the very heavy traffic of their main line.

TABLE XIV.—LIFE (IN MONTHS) OF 100-LB. RAILS—MAIN LINE, P. R.R.

Tangent	1°	2°	4°	6°	8°	9°
120 mo.	96	60	30	20	14	9

The curve indicating these values has also been shown in Fig. 17.

A comparison of these rates of wear apparently indicates that, although the rate of rail wear is less (under the given conditions) on the A. T. & S. F. than on the P. R.R., the *reduction* in rail life, by increasing the curvature from 4° to 9°, is far greater on the A. T. & S. F. than on the P. R.R. More important, however, is the agreement of both curves that they are *concave upward*. A considerable part of rail wear is independent of whether the track is curved or straight. The rails on a curved track are subject to all forms of wear which reduce the life of rails on a straight track and much other wear in addition. If we draw a straight horizontal line through the "120," the vertical distance down to the P. R.R. curve at any point indicates the *reduction* in the life of the rail on account of curvature. This reduction is less *per degree of curve* as the curvature is sharper. Although we do not know where the "tangent" ordinate belongs for the A. T. & S. F. curves, it is evident that the same principle holds good. This only verifies the theoretical deduction previously made that the longitudinal slipping (and the amount of rail wear it causes) is independent of the radius.

101. Rail-wear statistics on the Northern Pacific R.R.—Some five-year tests have just been made on the Northern Pacific Railroad to determine the actual wear of rails under a measured amount of traffic. Apparently one object of the investigation was to determine the effect of variation in the chemical composition of the rails. A pair of each of five types of rails were tested in each of eight situations; six of them being on the Pacific division and two on the Minnesota division. No attempt will be made here to analyze the effect of variation of chemical composition, but, since one of each kind of rail was used in each locality, the average of all rails for each locality will be considered as the typical rail for such an alinement and grade. The rails were actually weighed each year for five years, so that their actual loss in weight during each year's wear could be determined. The tonnage passing over these rails was systematically recorded. It varied for these eight localities between 27,021,227 and 29,862,738 tons. For uniformity in each case, the wear was reduced to the uniform basis of 10,000,000 tons. Even though the wear is not strictly proportional to the tonnage, the variation between 27,021,227 and 29,862,738 is not large enough to cause any serious error from this source. The wear of the rails on the tangents in per cent per 10,000,000 tons' duty is given in the following tabular form.

TABLE XV.—RAIL WEAR ON TANGENTS, NORTHERN PACIFIC R.R.

Five pairs of rails on first tangent, Pacific div.; grade, 0.3%.		Five pairs of rails on second tangent, Pacific div.; grade, 0.525%.		Five pairs of rails on third tangent, Minnesota div.; grade chiefly level at bottom of sag.	
Pct. loss in four years.	Pct. loss per 10,000,000 tons' duty.	Pct. loss in four years.	Pct. loss per 10,000,000 tons' duty.	Pct. loss in four years.	Pct. loss per 10,000,000 tons' duty.
1.800	.603	.960	.346	.451	.167
2.336	.783	.900	.324	.825	.305
1.806	.605	1.360	.490	1.135	.420
2.015	.676	1.256	.452	.822	.304
1.706	.572	1.807	.391	.280	.104
.....	.648	.....	.401	.....	.260

It may be at once noticed that the average loss in per cent per 10,000,000 tons' duty on the first tangent was

0.648%; on the second tangent it was only 0.401%. In the endeavor to discover the cause of the uniformly increased wear of the rails on the first tangent over that on the second tangent, the grade of the two tangents was considered, but the grade of the first tangent was 0.3%, while that of the second tangent was 0.525%. As rail wear is usually greater on steep grades than on flat grades, owing to the slipping of the driving-wheels when climbing the grades, or the possible skidding of the wheels when moving down the grade with brakes set, the results are here relatively contrary to what we would expect. The only apparent explanation of the increased rail wear on the 0.3% grade is that it occurs near the bottom of a very long down grade, where a train might have acquired a high velocity and where the wheels might have skidded in the attempt to hold the train, or where engines, hauling a train up grade, are doing their utmost (perhaps by using sand) to obtain a sufficiently high velocity to carry their trains by momentum over the long grade. In the case of the 0.525% grade this tangent occurs at the very upper end of the grade, where the velocity in either direction is probably lower than the average. Whether this is the true explanation, the relative wear on these two tangents for all makes of rails is uniformly as stated above.

102. Relation of rate of rail wear to the life-history of the rail.—The figures obtained during the above-described tests of rails on the Northern Pacific Railroad afford some very instructive and apparently reliable data regarding the rate of rail wear in its relation to the life-history of the rail. The rails were taken up and weighed each year for a period of four or five years; the loss of weight in pounds for each yearly interval then becomes known. It is usually stated that rail wear is comparatively small during the first half of the life of the rail and that the rate of wear grows in geometric ratio. It is usually supposed that this is more especially true of rails on sharp curves than on easy curves or on tangents. A study of the tabular values given in the report are interesting in this respect, for the figures seem to contradict this theory. The annual losses on the outer rails of 10° and 10° 30′ curves were as follows:

TABLE XVI.—YEARLY WEAR (IN POUNDS) OF OUTER RAILS—SHARP CURVES.

	1st Year.	2d Year.	3d Year.	4th Year.	5th Year.
10° curve; grade, 0.128%	13.75	13.75	11.75	18.25	21.0
	11.75	9.75	9.75	12.0	13.5
	13.25	9.75	9.75	16.5	21.25
	5.75	7.25	1.75	4.5	11.25
	9.75	7.25	5.75	7.0	15.75
Average...........	10.85	9.55	7.75	11.65	16.55
10° 30′ curve; grade, 0.3%...........	13.75	7.75	10.25	5.5	19.25
	13.5	5.25	9.25	19.25	6.25
	10.75	7.75	15.25	15.0	15.0
	12.0	4.25	4.75	15.0	2.5
	12.25	4.75	9.75	7.5	6.25
Average...........	12.45	5.95	9.85	12.45	9.85

Similar figures for the wear of rails on tangents are given in Table XVII.

So many rails are involved in the above tests that we can hardly ignore the indications given by the averages especially when the different lines of averages seem to vary by an approximately similar law. Apparently rail wear during the first year is greater than during the second and third years; during the fourth year it increases to about the same as during the first year, while the wear during the fifth year is usually far greater. If we ignore the three abnormally low values given for the fifth year on 10° 30′ curves, the average of the other seven values is 16.71 pounds per year, which is an increase over the fourth

TABLE XVII.—YEARLY WEAR (IN POUNDS) OF RAILS ON TANGENTS.

Grade.	1st Year.	2d Year.	3d Year.	4th Year.	5th Year.
0.3%............	3.0	3.0	3.0	3.25	6.0
	3.25	3.25	2.75	2.25	2.25
0.525%..........	2.5	4.25	0.75	1.50	9.0
	0.25	3.25	0.50	4.75	7.0
0.3%............	1.50	4.25	2.25	6.50	2.25
	4.75	4.75	2.25	4.25	6.25
0.525%..........	2.0	3.25	0.25	0.50	8.50
	2.25	2.75	0.0	0.75	10.25
0.3%............	3.75	2.25	0.75	2.50	1.25
	3.50	2.25	4.75	4.50	2.25
0.525%..........	1.75	3.75	0.75	1.0	2.25
	2.75	1.75	0.25	0.50	2.0
0.3%............	6.25	2.75	1.5	3.25	3.25
	5.25	0.25	4.25	5.75	1.75
0.525%..........	3.25	1.75	0.75	2.75	5.75
	2.75	3.25	0.25	3.25	14.0
0.3%............	2.75	2.75	2.75	3.5	6.25
	4.25	2.75	3.75	2.25	7.5
0.525%..........	2.5	3.25	0.5	0.25	4.75
	1.0	1.75	2.75	3.5	6.25
Average, 0.3%.....	3.82	2.82	2.80	3.80	3.90
" 0.525%...	2.10	2.90	0.67	1.87	6.97
General average.....	2.96	2.86	1.74	2.84	5.94

year such as we might expect. It may be noticed in passing that all of the rails on the 10° curves were noted as being "badly worn" and that the rails on the 10° 30′ curves were actually replaced. The rails on the 10° 30′ curve averaged 648 pounds in weight and they had lost an average of nearly 50 pounds, or about 8%, before being replaced. The rails on the 10° curve averaged 679 pounds in weight and they had lost a little over 56 pounds apiece, which was little over 8% on their weight. They had not been actually renewed, although they were indicated as "badly worn."

103. Rail wear on curves.—In Table XVII is given an analysis of the figures furnished for the rail wear on various curves of the Pacific division of the Northern

Pacific Railroad. The method adopted was to determine the percentage loss in four years. This percentage was divided by the tonnage (varying between 27,021,227 and 29,862,738 tons) to reduce it to the uniform basis of the wear for 10,000,000 tons' duty. By dividing the quantities in column 3 by the average percentage loss (0.525%) on two tangents subject to the same traffic, of this same division, we have the ratio of the rail wear on a curve to the rail wear on the average tangent. Subtracting one from each one of the quantities in column 4 we have

Table XVIII.—Rail Wear on Curves—Northern Pacific R.R., Pac. Div.

Degree of curve.	Pct. loss in four years.	Pct. loss 10,000,000 tons' duty.	Col. 3 ÷.525.	Excess over one.	Excess per degree.	Average excess per degree.
4° 31'. . . .	2.675	0.964	1.838	0.838	.185	.150
	2.970	1.070	2.038	1.038	.230	
	2.912	1.049	1.999	0.999	.221	
	1.781	0.642	1.223	0.223	.049	
	1.877	0.676	1.288	0.288	.064	
5° 0'.	3.500	1.173	2.235	1.235	.247	.270
	3.271	1.096	2.087	1.087	.217	
	4.349	1.450	2.761	1.761	.352	
	2.857	0.957	1.823	0.823	.165	
	4.450	1.491	2.840	1.840	.368	
10° 0'	5.150	1.855	3.534	2.534	.253	.188
	4.417	1.590	3.030	2.030	.203	
	6.205	2.238	4.265	3.265	.326	
	2.087	0.751	1.430	0.430	.043	
	3.122	1.124	2.141	1.141	.114	
10° 30' . . .	6.200	2.080	3.960	2.960	.282	.213
	6.022	2.020	3.850	2.850	.272	
	5.610	1.882	3.588	2.588	.247	
	3.704	1.241	2.365	1.365	.130	
	3.795	1.272	2.423	1.423	.136	

the *excess* wear, which may be considered due to curvature alone. By dividing these quantities in column 5 by the degree of the curve we have the excess per degree.

The average of the five values in each case is given in column 7. The significance of these numbers in column 7 may be interpreted as follows: .150, for example, means that the *excess* wear per degree of curve on the various rails of the 4° 31′ curve averaged $\frac{150}{1000}$ of the wear on an average tangent. The other figures in the last column are to be interpreted similarly. The 4° 31′ curve was on a 0.525% grade, the 5° curve was on a 0.3% grade, the 10° curve was on a 0.128% grade, and the 10° 30′ curve was on a 0.3% grade. The rate of grade on these curves evidently does not account for the variations in these values. It is quite apparent that the rail wear per degree of curve for the sharper curves does not increase with the curvature, and it is more than likely that it diminishes, as was indicated by the diagrams given in § 100.

A similar computation was made from the results of the wear on a 3° curve on the Minnesota division. See Table XIX.

TABLE XIX.—RAIL WEAR ON CURVES—NORTHERN PACIFIC RAILROAD MINNESOTA DIVISION.

Degree of curve.	Pct. loss in four years.	Pct. loss 10,000,000 tons' duty.	Col. 3 ÷ .260.	Excess over one.	Excess per degree.	Average excess per degree.
3° 0′	1.208	.447	1.718	0.718	.239	.310
	1.030	.392	1.507	0.507	.169	
	1.538	.569	2.188	1.188	.396	
	1.314	.487	1.872	0.872	.291	
	1.657	.613	2.358	1.358	.453	

Here the average excess per degree amounted to 31% of the rail wear on the tangent. The average percentage of excess per degree on the curves of the Pacific division was 20.5%; for the one curve on the Minnesota division it was 31%; allowing the average for the four curves a weight of four and giving a weight of one for the curve on the Minnesota division, the weighted mean is 32.6%. Anticipating a demand in a future chapter (Chapter XIII) for the effect of curvature on the cost of the renewal of the rails, we might state, as an approximate average figure, that, since the excess rail wear per degree of curve does not seem to increase with the curvature, it is a safe conclusion to say that it varies with the degree or curvature, and that therefore the *excess* rail wear on a 10° curve will be 326% of the rail wear on a tangent.

Economics of Ties.

104. Importance of the subject.—The cost of rails is frequently the largest single item in the cost of constructing a railroad, the cost of the ties usually being less than one-half the cost of the rails. This familiar fact is apt to cause the engineer to lose sight of the fact that the relative cost for maintenance is reversed. For the last ten years the average cost of maintaining ties on the railroads of the country has been a little over twice the cost of maintaining the rails. The amount actually spent in 1904 was nearly $34,000,000, or nearly 3% of the total operating expenses. The enormous number of ties annually consumed in track maintenance is so depleting the forests of the country that the price of timber has advanced very greatly during the last few years, and it has become a question of national importance which is engaging the attention of the United States Government. Therefore any method which will increase the life of a wooden tie is a matter of great importance, not only to the railroads but also to the community in general, since the whole lumber industry has been very largely affected by the use of timber for railroad-ties.

105. Methods of deterioration and failure of ties.—The failure of ties is due to some one or to a combination of a large number of causes. First, the wood may decay.

Second, the wood may be so soft that the holding power of the spikes may be small and this requires that the spikes must be frequently re-driven in order to hold the rails. Since the tie must be placed symmetrically under the rails, the available area for driving spikes is very limited, and it sometimes happens that an otherwise sound tie must be taken out because it has been "spike-killed." Third, the tie may be so soft that it is crushed by the concentrated pressure of the rail-flange and especially by the pressure of the outer flange of the outer rail on curves. This form of destruction is largely obviated by the comparatively inexpensive device of tie-plates.

106. The actual cost of a tie.—The actual cost of a tie equals the total of several items, of which the first cost is but one item. It must be transported from the place of sale and delivery to the road to the place where it is to be used. A certain amount of, track-labor is necessary to place the tie in the track. A considerable amount of track-labor is necessary to maintain the track at a proper surface. The amount of this labor will depend considerably on the length, width and weight of the tie, since a large heavy tie has such a hold in the ballast that it is not so easily disturbed by the passage of trains. Since the cost of track-labor is such a very important item in the total cost of a tie, a tie which can be kept in the track for a greater length of time and with less work for maintenance may be far more economical in the long run than a tie which has cost less money. The annual cost of a system of ties may be considered as the sum of (*a*) the interest on the first cost, (*b*) the annual sinking-fund that would buy a new tie at the end of its life, and (*c*) the average annual cost of maintenance for the life of the tie which includes the cost of laying and the considerable amount of subsequent tamping that must be done until the tie is fairly settled in the road-bed. The following very conservative estimate of the relative cost of untreated ties and ties which have been treated chemically is given as follows: the cost of the untreated tie is estimated at 40 c., while the cost of the chemical treatment is assumed to be 25 c., making the total cost of the treated tie 65 c. The life of the untreated tie is assumed to be seven years and that of the treated tie fourteen years. The annual interest on the first cost estimated at 4% will therefore be 1.6 and 2.6 c. respectively. The sinking-fund at 4% which would renew each tie at the given cost at the end of its estimated life will be 5.1 and 3.6 c. respectively. The average annual cost of maintenance is very difficult to estimate, but, since we are seeking a comparison rather than a definite estimate of cost, all that we need to know is the excess of the cost of one method of construction over the other. Owing to the impracticability of giving a definite figure for item (*c*) we will assume that it balances for the two methods, but with the understanding that the advantage is very distinctly with the treated tie and that the advantage extends not only to the comparative cost of trackwork but also the indefinite saving in operating expenses, due to less jar of the rolling-stock on a smoother track, less cost of repairs, less consumption of energy by the locomotive, and all the advantages of a smoother track. Collecting these items we have the tabulated form as follows:

	Untreated tie.	Treated tie.
Original cost.	40 cents	65 cents
Life (assumed at).	7 years	14 years
Item (*a*)—interest on first cost at 4%.	1.6 cents	2.6 cents
“ (*b*)—sinking-fund at 4%.	5.1 “	3.6 “
“ (*c*)—(considered here as balanced).	. . . .	. . . .
Average annual cost (except item (*c*)).	6.7 cents	6.2 cents

107. Chemical treatment of ties.—The methods of chemical treatment of ties will not be here discussed, as it may be found in numerous text-books. It is not easy to obtain an accurate estimate of the effect of chemical treatment, unless reliable figures showing the total life in the track of a very large number of ties are obtainable. It frequently happens that, owing to some imperfection in the tie or some error in its treatment, a treated tie may not last even as long as a wooden untreated tie. It is only by obtaining the average figures for a very large number of ties (at least several thousand) that a true measure of the economy of chemical treatment can be obtained. The lack of accurate figures is due largely to the fact that it is practically a difficult matter to keep track of the actual life of the ties. Chalk-marks, and even numbers stamped with dies, are easily obliterated in a few years. Marking the ties with tacks arranged to form letters seems to be the best method, and it has therefore been largely adopted by railroads which have determinedly made a study of this question. But such a method involves trouble and work which few roads have been willing to make. Even when figures have been obtained regarding the life of ties, it will be found that, of a lot of ties which are supposed to be uniform and whose average life is supposed to be say seven years, a considerable percentage of the ties may need to be removed in two or three years, while a very considerable percentage of them may still be in the track after 12 or 15 years' service. Similar figures are found for the life of chemically treated ties, some of them requiring removal after a very few years' service, while others will last much longer than could be claimed by the promoters of that particular system of tie treatment. It therefore becomes necessary in comparing the life of untreated ties with treated ties, or in comparing the life of ties treated with different methods of treatment, to compare the percentages of removals after a given period of years. It practically amounts to the same thing to determine for each kind of tie or each method of treatment a curve, showing the number of ties as one set of ordinates, and their corresponding life for the other. The comparison of such curves will show which manner of treatment gives the best results.

108. Comparative value of cross-ties of different materials.—Through the courtesy of Mr. W. C. Cushing, Chief Engineer of Maintenance of Way, Pennsylvania Lines West of Pittsburg, S. W. System, the author is enabled to quote very largely from a paper published by him in Bulletin No. 75 of the American Railway Engineering and Maintenance of Way Association. Mr. Cushing made an investigation, with a view to determining, as closely as possible, the relative value of concrete and steel cross-ties, taking cost and prospective life into account, as compared with the wooden cross-ties at present in use. The author states that "some of the data used are costs established from actual practice and from reliable information given, while in other cases assumptions have been made after examining the most reliable information available. It is quite true, of course, that these figures cannot be considered as absolutely correct, but it is believed by the writer that they are fairly trustworthy." The author develops his values on the basis of the formula proposed by Mr. S. Whinery, in the "Railroad Gazette" for November 11, 1904. In order to eliminate any difference due to variability of tie-spacing, all results have been reduced to the cost per linear foot of track.

This annual cost per linear foot of track may be expressed algebraically thus:

Let x = the required annual cost of ties per linear foot of track;

c = the first cost in the track per linear foot of track;
v = the value of the worn-out tie per linear foot of track;
L = the useful life of the tie in years.
i = the rate of interest = the interest on $1.00 for one year;
s = an annual payment into a sinking-fund which at i rate of interest for L years will amount to one dollar (s can be taken directly from tables such as that on page 16 of Kent's Mechanical Engineers' Pocket-book):

Then $x = ci + (c - v)s.$

If $v = 0$, then $x = c(i + s).$

On the basis of the above formula, Mr. Cushing made three tabulations which have not been copied. Table I shows the "cost delivered which a white-oak tie lasting 10 years must reach before it will be economical to use any of the ties heading the columns." The ties considered in this table were made of white oak untreated, inferior woods treated with zinc-chloride and zinc-tannin, but using no tie-plates, also ties of inferior woods using tie-plates and treated with zinc-chloride, zinc-tannin, zinc-creosote, and with creosote costing 30 and 85 cents per tie, also steel ties costing $1.75 and $2.50; also concrete ties costing $1.50 and $2.25. Table II shows "how long ties of different materials must last in order to be as economical as white oak costing 70 cents and lasting ten years." Table III shows "first cost which can be paid for different kinds of ties in order to be as economical as white oak costing 70 cents and lasting ten years." The kinds of tie considered and also their chemical treatment, if any, are the same in Tables II and III as were stated for Table I. From these various tables Mr. Cushing made the following deductions.

DEDUCTIONS FROM TABLE I.

(1) With white-oak ties costing 70 cents delivered on the railroad, it is economical at the present time to buy inferior woods at a price not to exceed 50 cents, have them treated with zinc-chloride or zinc-tannin, lay them in the tracks without the use of tie-plates (except where it is necessary to use them on oak ties), and use a standard railroad spike. A life of ten (10) or eleven (11) years has been found to be a maximum for such ties without the use of tie-plates and better fastenings, and if the life of ten (10) years is not attained, there will be that much loss to the company.

(2) When a white-oak tie reaches a cost of 86 or 87 cents delivered on the railroad, it will be economical to use the zinc-creosote process, or straight creosote costing 30 cents, if the tie costs 46 cents delivered on the railroad and will last (16) sixteen years; or it will be economical to use straight creosoting costing 85 cents for treatment if the tie can be made to last thirty (30) years, which is French practice, before the oak tie reaches a cost of 80 cents delivered on the railroad. In both of these cases it is assumed that tie-plates, wood screws, and helical linings are used because ties cannot be made to last more than ten (10) or twelve (12) years without the use of proper fastenings, since, otherwise, the tie will be destroyed by mechanical wear. It is necessary, therefore, to use improved fastenings when we expect to obtain a life of ties greater than ten (10) or eleven (11) years.

It will also be economical to use a steel tie costing $1.75 delivered if it will last twenty (20) years.

(3) When the white-oak tie reaches a cost of 90 cents delivered on the railroad, it will be economical to use either ties of inferior woods treated with zinc-tannin if a life of fourteen (14) years can be obtained, the improved

fastenings being used, or a concrete tie costing $1.50 if it will last twenty (20) years.

(4) When the price of white-oak ties reaches $1, it will be economical to use a steel tie costing $2.50 if it will last thirty (30) years, a concrete tie costing $2.25 if it will last thirty (30) years, or an inferior wood tie treated with zinc-chloride if a life of twelve (12) years can be obtained.

DEDUCTIONS FROM TABLE II.

(5) With ties of inferior woods costing 46 cents delivered on the railroad we must obtain a life of from eighteen (18) to twenty (20) years, whether treated with zinc-chloride, zinc-tannin, or zinc-creosote, to make them as economical as white-oak ties costing 70 cents. It is assumed, of course, that they must have the most approved fastenings in order to attain an age as great as that.

(6) With inferior woods costing 46 cents delivered on the railroad, and if the creosoting costs 30 cents, it will be necessary for us to obtain a life of twenty-one (21) years in order to make them as economical as white-oak ties costing 70 cents delivered.

(7) With inferior wood ties costing 46 cents delivered, and with the creosote treatment costing 85 cents, as in French practice, it will be necessary for us to obtain a life of thirty-six (36) years from the ties in order to make them as economical as white-oak ties costing 70 cents delivered.

(8) With steel ties costing $1.75 each delivered, it will be necessary for us to obtain a life of twenty-eight and one-half (28½) years in order to have them as economical as white-oak ties costing 70 cents delivered. This price is a little less than the cost of the Buehrer steel ties in the tracks at Emsworth.

(9) With concrete ties costing $1.50 each delivered, it will be necessary for them to last twenty-eight (28) years before they will be as economical as the white-oak ties costing 70 cents delivered.

(10) With steel ties costing $2.50 delivered and concrete ties costing $2.25 delivered, which are approximately the prices of the Seitz steel tie and the Buehrer concrete tie in the tracks at Emsworth, it is necessary for them to last over fifty (50) years each in order to make them as economical as the white-oak ties costing 70 cents delivered.

DEDUCTIONS FROM TABLE III.

(11) In order to make treated inferior woods as economical as white oak costing 70 cents delivered, when the treated ties are equipped with proper fastenings in order to make them last as long as has been found practicable by experience, we can only afford to pay for the ties delivered on the railroad, 10 cents each when treated with zinc-chloride; 20 cents each when treated with zinc-tannin or creosoted at 30 cents; 23 cents each when treated with zinc-creosote, and 29 cents each when creosoted in accordance with French practice.

(12) In order to make them as economical as white-oak ties costing 70 cents delivered, we can only afford to pay $1.48 each for steel ties which last twenty (20) years, and $1.79 each when lasting thirty (30) years.

(13) In order to make them as economical as white-oak ties costing 70 cents delivered, we can only afford to pay, as first cost of concrete ties delivered, $1.15 each if they last twenty (20) years, and $1.57 each if they last thirty (30) years.

(14) We know nothing about the life of concrete ties, and it is at least very desirable to experiment with them for yard and side tracks, even though we do not use them in the main tracks, because they might lie undisturbed in

yard tracks for many more years than they would in main tracks.

(15) When white-oak ties are costing 70 cents delivered (about present prices), we can afford to buy inferior oak and other hard woods at 45 to 50 cents (present prices) and have them treated with the zinc-tannin or zinc-chloride processes, and only use common spike fastenings.

109. Economy due to form of tie.—The standard practice in this country, especially in parts of it where rigid economy in the use of ties is not essential, is to use a tie with a rectangular cross-section. An attempt at economy has been made by adopting a form of tie which would permit a greater number of ties to be sawed from the same tree trunk. The Great Northern Railroad has been experimenting with triangular ties, cut by sawing the maximum square obtained from a tree trunk into four parts by cutting through the diagonals. In this way four triangular ties would be obtained from a tree trunk, as shown

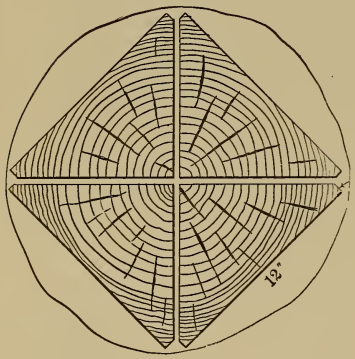


Fig. 18.—Method of cutting four triangular ties from one tree.

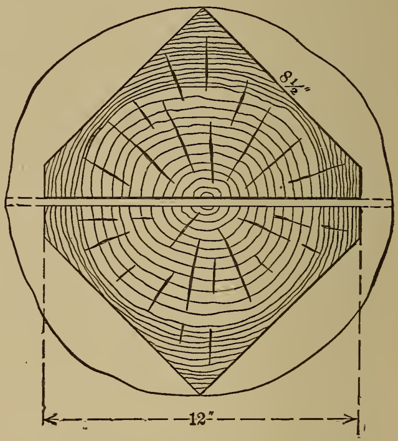


Fig. 19.—Method of cutting two triangular ties from one tree.

in Fig. 18, from which only two rectangular ties could be obtained. If the tree trunk is so small that the cross-sections of the ties would be too small when cut in this form, then two triangular ties would be cut from the trunk, as shown in Fig. 19. When tie-plates are used, the upper corners of an ordinary rectangular tie are of little use, and there is but little, if any, objection to sawing the tie so as to leave off the corners, as shown in Fig. 20. While the method of triangular ties is unquestionably economical as to the number of ties which can be produced from given sizes of timber, the ties themselves are objectionable, since the wood is apt to split and check very badly, and the durability is very greatly diminished. Economy is also possible by studying the exact dimensions of each log to determine whether it is possible to cut planks from the slabs on the outside. Formerly the slabs were wasted. The increase in the cost of lumber has justified the effort to save them.

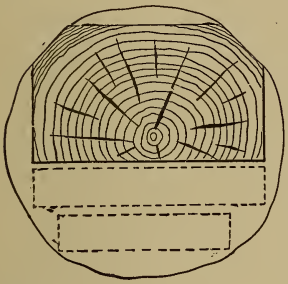


Fig. 20.—One tie and one or more planks from one tree.

110. Protection against wear by using tie-plates.—Although it is found that a soft-wood tie is more easily impregnated with chemicals, and thereby insured against rapid decay, the tie is not thereby protected against mechanical wear of the rail on the tie. This wear is largely prevented by use of tie-plates. Tie-plates originally had a flat lower surface, but, since the plates were made very thin, it was found that they buckled under the pressure of the rail. It was then thought necessary to use some form of corrugation or prong which should fasten the tie-plate in the tie. It has been found that even these corrugations will not secure the plate solidly to the tie, but that the plate will rock on the tie with the movement of the rail, thereby enlarging the hole made by the corrugation or prong. It has been found in many cases that this actually led to abnormal wear and decay immediately under the tie-plate, which caused the removal of the tie when it was otherwise perfectly sound. On this account the Southern Pacific and the Pennsylvania Railroads, as well as most European railroads, have adopted tie plates which have no corrugations or prongs on the lower surface.

During recent years experiments have been made on European railroads, and to some extent in this country, on the use of very thin strips of creosoted wood, which are placed immediately under the rails. These strips are as wide as the base of the rail, as long as the width of the tie, and not more than ¼ inch thick; sometimes they are as thin as ⅛ inch. They are very cheap and can readily be renewed. The theory of their advantage is based on the fact that the inevitable wave-motion of the rail on the tie results either in the rail sliding over the tie-plate or in the tie-plate rocking over the tie. As long as the tie-plate rigidly retains its hold on the tie there is little or no trouble; but when the tie-plate becomes loose, then it moves on the tie and wears it as has been described. The wooden tie-plate will invariably stick to the wooden tie and the rail will slide over the tie-plate. The wear then consists entirely of that due to the rail sliding over the tie-plate, and this results merely in wearing out the wooden tie-plate, which is readily and cheaply renewed.

111. **Use of screw-spikes.**—The ordinary track-spikes are very largely responsible for the removal of ties, since they induce decay around the spike-hole even if the tie is not spike-killed by the frequent re-driving of spikes. Even the treated ties are ruined by the spikes, especially

when the ties have been treated with a chemical which is soluble in water, since the water will soak into the spike-hole and leach the chemical, which then leaves the wood-fibers unprotected and subject to decay. The best substitute for spikes, and the method which has been frequently adopted, is the screw-spike. Although the details of their design as adopted by various roads have a considerable variation, they all agree essentially in having a length of about five or six inches; have a square or hexagonal head so that they can be screwed with a suitable wrench; they taper to a blunt point, and have a screw-thread similar to those used for any wooden screw. Of course one essential to the form of the head is that it shall have a flange wide enough to extend over the base of the rail and thus hold it down. It is essential that a hole, somewhat smaller than the diameter of the spike, shall be previously drilled into the tie. When a large number of screw-spikes are to be placed, the work is accomplished by a drilling-machine, which not only does the work more accurately but with greater speed. It has been found by actual test that such machines can put in two screw-spikes while three ordinary spikes are being driven. Even the additional time required is much more than saved by the reduction in track-work made possible by the use of screw-spikes. Although the holding-power of screw-spikes, compared with ordinary spikes, varies with the character of the wood, the average of a large number of tests showed that the relative holding-power of screw-spikes and common spikes in white oak was as

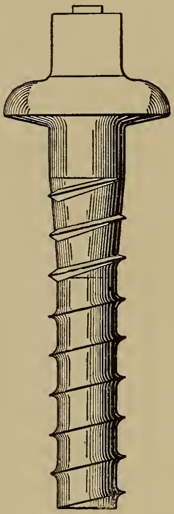


FIG. 21.
Screw-spike.

1.87 : 1, while in long-leaf pine the ratio was as 4.63 :1. This shows that screw-spikes are especially advantageous in soft-wood ties, which are so readily subject to spike-killing.

112. **Use of dowels.**—Another device for retarding the destruction of ties is the invention of a French engineer and consists in using a creosoted piece of wood, into which the spike, which may be either a common spike or a screw-spike, is inserted. A cylindrical hole is first bored into the tie; following this a shaper cuts a screw-thread in the sides of the hole already bored; the wooden dowels, which are already provided with a corresponding screw-thread, are then screwed in the tie. Since the upper part of the dowel is conical, the dowel is readily screwed down until it fits the hole, and there is no danger that water will soak in around the dowel. After the dowel is in place, another machine cuts it off even with the top of the tie. The dowel has a hole through the center which is bored the proper size for the insertion of the screw-spike.

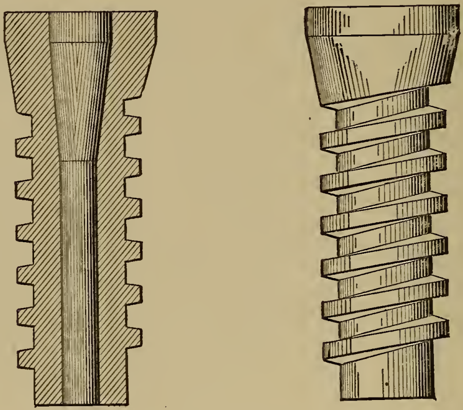


Fig. 22.—Wooden dowels for ties.

Usually a hole the proper size is provided, even when common spikes are to be used. It is found that the comparative resistance to displacement, both lateral and vertical, when dowels are used with soft-wood ties is very remarkable, as it very largely increases the holding-power of the spikes and thus retards one of the most common causes of tie deterioration.

CHAPTER X.

TRAIN RESISTANCE.

113. Classification of the various forms.—The various resistances which must be overcome by the power of the locomotive may be classified as follows:

(*a*) *Resistance and losses internal to the locomotive,* which include friction of the valve-gear, piston- and connecting-rods, journal friction of the drivers, also all the loss due to radiation, condensation, friction of the steam in the passages, etc. In short, these resistances and losses are the sum total of the lost energy by which the power at the circumference of the drivers is less than the power developed by the boiler.

(*b*) *Velocity resistances,* which include the atmospheric resistances on the ends and sides of the train, the oscillation and concussion resistances due to uneven track, etc.

(*c*) *Wheel resistances,* which include the rolling friction between wheels and the rails of *all* the wheels (including the drivers), also the journal friction of all the axles *except* those of the drivers.

(*d*) *Grade and curve resistances,* which include those resistances which are due to grades and curves and which are not found on a straight and level track.

(*e*) *Brake resistances.* These consist of that very considerable proportion of the power developed by the locomotive, which is consumed by the brakes.

(*f*) *Inertia resistances.* From one standpoint the energy expended in overcoming inertia should not be considered as a train resistance, since it is stored up in the train as kinetic energy which is afterward utilized in doing useful work, or it is consumed by the application of brakes; but, in a discussion of the demands on the tractive power of the engine, one of the chief items is the energy required to rapidly give to a starting train its normal velocity, and therefore this item must be considered, since a discussion of train resistances is virtually a discussion of the power required from the locomotive to overcome all the resistances.

114. Resistances internal to the locomotive.—These are the resistances which do not tax the adhesion of the drivers to the rails. If the engine were considered as lifted from the rails and made to drive a belt placed round the drivers, then all the power that reached the belt would be the power that is ordinarily available for adhesion, while the remainder would be that consumed internally by the engine. The modern locomotive testing-plant mounts the locomotive on a series of wheels placed immediately under the driving-wheels. The motion of the driving-wheels turns the wheels on which they rest, and thereby operates dynamometers which measure the power developed. The locomotive itself is rigidly secured against any horizontal motion. The power developed in the cylinders may be obtained by taking indicator-diagrams which show the actual steam-pressure in the cylinder at any part of the stroke. From such a diagram the average unit steam-pressure is easily obtained, and this average pressure multiplied by the length of the stroke and by the net area of the piston gives the energy developed by one half-stroke of one piston. Four times this product, divided by 550 and multiplied by the number of revolutions per second, gives the "indicated horse-power." Even this calculation gives merely the power behind the piston, which is several per cent greater than the power which reaches the circumference of the drivers, owing to the friction of the piston, piston-rod, cross-head, connecting-rod bearings, and driving-wheel journals.

By measuring the amount of water used and turned into steam and by noting the boiler pressure, the energy possessed by the steam used is readily computed. The indicator-diagrams will show the amount of steam that has been effective in producing power in the cylinders. The steam accounted for by the indicator-diagrams will ordinarily amount to from 80 to 85% of the steam developed by the boiler; the other 15 or 20% represents the loss of energy due to radiation, condensation, etc. The power consumed by the engine in frictional resistances is considerably greater when the engine is hauling a train than when it is merely running light. It has been estimated that an engine when running light will consume about 11% of the power which it will develop when it is working to the limit of its capacity in hauling a train, but it has also been determined that when it is doing its maximum work about 15 to 16% of the power developed by the pistons is consumed by the engine, leaving about 84 to 85% for the train. This may be determined by a comparison of the energy developed by the pistons, as computed from the indicator-diagrams, with the amount of energy transmitted behind the tender as measured by a dynamometer at the rear of the tender.

115. Velocity resistances. (*a*) *Atmospheric.*—These consist of the head and tail resistances and the side resistance. The head and tail resistances are nearly constant for all trains of given velocity, varying but slightly with the varying cross-section of engines and cars. The side resistance varies with the length of the train and the character of the cars, whether box-cars or flats. Vestibuling the cars of passenger-trains has had a considerable effect in reducing the side resistances by preventing much of the eddying of air-currents between the cars, although this is one of the least of the advantages of vestibuling. Atmospheric resistance is generally assumed to vary as the square of the velocity, and, although this may be nearly true, it has been experimentally demonstrated to be at least inaccurate. The head resistance is frequently assumed to vary as the area of the cross-section, but this has been definitely demonstrated to be very far from true. A freight-train, composed partly of flat-cars and partly of box-cars, will encounter considerably more atmospheric resistance than a train consisting exclusively of either type of car, other things being equal. On account of the extreme variation in the making-up of freight-trains no accurate figures regarding atmospheric resistance would be of much value, and this probably explains why more effort has not been made to obtain accurate determinations of this form of resistance. In the comparatively few experiments which have been made, the head resistance has been assumed to vary as the cross-sectional area and also as the square of the velocity. The results obtained by different experimenters have been so discordant as to be of little value. The discrepancies are due to the fact that both of the assumptions regarding the variation of the atmospheric resistances are inaccurate.

(*b*) *Oscillatory and concussive.*—These resistances are considered to vary as the square of the velocity. Probably this is nearly, if not quite, correct, on the general principle that such resistances consist of a series of impacts. The laws of mechanics tell us that the force of impact varies as the square of the velocity. These impacts are due to irregularities in the track and to the effect of the yielding of the rails and ties in a ballast which is not homogeneous in character nor absolutely uniform in its elasticity. Even though it were possible to make a precise determination of the amount of this resistance in any particular case, the value obtained would only be true for that particular piece of track and for the particular degree of excellence or defect which the track *then* possessed. The general improvement in track maintenance during late years has had a large influence in increasing the possible train-load by decreasing the train resistance. The expenditure of money to improve track will give a road thus improved an advantage over a competing road with a poorer track by reducing train resistance and thus reducing the cost of handling traffic. Although it is almost impossible to determine accurately the effect of a given expenditure in track improvement in reducing track resistance, it is significant to note that the resistances per ton which were measured by experimenters even 25 years ago were far higher than those obtained on the improved tracks of the present day.

116. **Wheel resistance.**—(*a*) *Rolling friction of the wheels.* To determine experimentally the rolling friction of wheels, apart from all journal friction, is a very difficult matter and has never been satisfactorily accomplished. Another practical difficulty is that the rolling resistance on a track is more or less intimately connected with the yielding of the rail, which is due not only to its own elasticity but to the yielding under it of the ties and ballast. Theory as well as practice shows that the higher and more perfect the elasticity of the wheel and of the surface on which it rolls the less will be the rolling friction. The determination, even if it could be made, would be chiefly of theoretic interest. The rolling friction is only a very insignificant part of the total train resistance. From the nature of the case no great reduction of the rolling friction by any device is possible. The use of harder rails with higher elasticity would probably have some effect in reducing it, but this effect would be so very small that it should hardly

be considered in comparison with the effect of that added hardness and elasticity on the cost of the rails and the rate of rail wear.

(*b*) *Journal friction of the axles.* The energy used up in this form of resistance has been studied quite extensively by means of the measurement of the force required to turn an axle in its bearings under various conditions of pressure, speed, extent of lubrication, and temperature. It may be measured quite accurately by loading a pendulum with any desired weight and hanging the pendulum on to the axle. The axle is then turned at any desired speed of rotation, which is easily measured. The deviation of the pendulum from the vertical position gives a measure of the circumferential resistance.

The following laws have been fairly well established: (1) The coefficient of friction increases as the pressure diminishes. (2) It is higher at very slow speed, gradually diminishing to a minimum at a speed corresponding to a train velocity of about 10 miles per hour, then slowly increasing with the speed. (3) It is very dependent on the perfection of the lubrication, it being reduced to $\frac{1}{6}$ or $\frac{1}{10}$ when the axle is lubricated by a bath of oil rather than by a mere pad or wad of waste on one side of the journal. (4) It is lower at high temperatures and vice versa.

The practical effect of these laws is shown by the observed facts that (1) loaded cars have a far less resistance *per ton* than unloaded cars. (2) When starting a train the resistance may be as much as 16 or even 20 pounds per ton, notwithstanding the fact that the velocity resistances are practically zero. At a speed of two miles per hour it will drop to about one-half of this figure, and at seven miles per hour the resistance of loaded cars will drop to between 4 and 5 pounds per ton. (3) The journal resistance is so very greatly reduced by higher temperature (which results from the increased velocity) that it largely neutralizes the increase in the velocity resistances, and tends to make the total resistance uniform for a considerable range of low velocities, say between 7 and 35 miles per hour. (4) As a corollary to the above, it is found that the resistance at any given speed, say 20 miles per hour, is less, if the velocity has been reduced to that figure from some higher velocity, than it is if the velocity has been increased to 20 miles per hour from a lower velocity. (5) It has been observed that freight-train loads must frequently be cut down in winter by about 10 or 15% of the loads that the same engine can haul over the same track in summer. This is doubtless due chiefly to the reduction of temperature of the journal-bearings and the consequent addition to the journal resistance, in spite of the fact that the tractive resistance will probably be less over a hard frozen road-bed, provided that the track has been kept in uniform surface.

Roller bearings for cars have been used to some extent. It has been found that they very greatly reduce the starting resistance, but that their advantages grow less and less as the velocity increases. The effect of the adoption of this device on car repairs and maintenance has not yet been determined on a large scale, and the ultimate economy is still uncertain.

117. Grade resistance.—The amount of this may be computed with mathematical exactness. Since the tractive resistances are computed separately, we merely have to compute the tendency of the wheels to roll down the grade, or the resistances to pulling them up the grade, which are exactly equal when the frictional resistance is zero or when it is otherwise provided for. Assume that a ball or cylinder (Fig. 23) is being drawn up an inclined plane. If we represent its weight by W, as measured graphically by the line W in the figure, then N will measure the normal pressure against the plane, and G will measure the force required to draw it up the plane with a uniform velocity. It also measures the tendency of the weight to roll down the plane. From similar triangles we may write the proportion

$$G:W::h:d \quad \text{or} \quad G=\frac{Wh}{d}. \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

In the diagram d is very much larger than c, but, as will

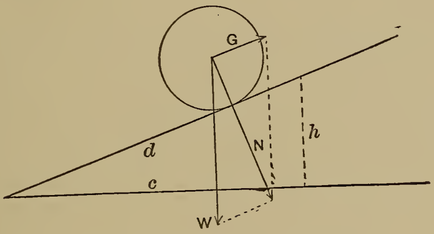


FIG. 23.—Grade resistance.

be shown, c is so nearly equal to d on all practicable railroad grades that there is no appreciable error in substituting c for d, and write the equation $G=\frac{Wh}{d}$. But $\frac{h}{c}$ equals the rate of grade. Therefore we have the very simple and mathematically exact relation that the grade resistance $G=W$ times the rate of grade. In order to appreciate exactly the extent of the approximation in assuming that the slope distance equals its horizontal projection, the percentage of the slope distance to the horizontal projection is given in the tabular form on page 186. Incidentally the tabular form shows the amount of error involved when we measure with the tape lying on the ground instead of holding it horizontally. Since almost all railroad grades are less than 2% (where the error is but .02 of 1%) and anything in excess of 4% is unheard-of for normal construction, the error in the approximation is generally too small for practical consideration.

Grade in per cent.	1	2	3	4	5	6	7	8	9	10
$\frac{\text{Slope dist.}}{\text{hor. dist.}}\times 100$..........	100.005	100.020	100.045	100.080	100.125	100.180	100.245	100.319	100.404	100.499

If the rate of grade is 1:100, G equals $W\times\frac{1}{100}$, i.e., $G=20$ pounds per ton; therefore, for *any* per cent of grade, $G=(20\times$ per cent of grade) pounds per ton. When moving up and down grade this force G must be overcome in addition to all the other resistances. When moving down a grade the force G assists the motion, and the net force tending to move the car or train down the grade equals G minus the resisting forces. If the resisting forces are less than G, then the train will keep moving down the grade, and its velocity will increase until the added resistance to increased velocity just equals G. The train will then move at this uniform velocity as long as such conditions remain constant. If the resistance of a train averaged 6 pounds per ton for a velocity of 20 miles per hour and the train were started on a down grade of 0.3% at this velocity, then it would move indefinitely at this speed down such a grade. If a train were started down a 1% grade at a velocity of say 10 miles per hour, the grade force will equal 20 pounds per ton on the 1% grade. Under such conditions the velocity of the train would increase until the velocity resistances would equal 20 pounds per ton. The precise speed at which this will occur depends on whether cars are loaded or empty and on various other conditions which affect train resistance, but the velocity would probably be very high, perhaps 60 or 70 miles per hour. Since this would be too great a speed for safety with freight-cars, a 1% grade of indefinite length can never be operated without the use of brakes. As developed later in the chapters on Grade, the necessary use of brakes on a down grade is one of the objections to grade, in addition to the resistance to moving up the grade.

118. Curve resistance.—It is exceedingly difficult to obtain experimental data showing the resistance in pounds per ton which is due to curvature. Mr. J. F. Aspinall, an English engineer, who has made many elaborate experiments on train resistance, has commented on this difficulty substantially as follows: When the experimental train enters the curve the engine encounters the additional resistance first, which decreases its velocity slightly, and the draw-bar pull actually diminishes instead of increases. As the train gradually moves on to the curve, the draw-bar pull increases until it will settle to some definite value after the entire train is on the curve; but, unless the curve is very long or the speed very slow, the engine will begin to leave the curve very soon afterward. On the track on which Mr. Aspinall conducted his experiments, these conditions existed to such an extent that no reliable computations of the curve resistance were possible.

Mr. G. R. Henderson uses the value 0.5 pound per ton per degree of curve. This is based on the assumption that the resistance varies directly as the degree of curvature. Although precise figures for the curve resistance are so scarce, it is definitely known that the total curve resistance does *not* increase as fast as the degree of curve. While the values given by Mr. Henderson's formula may be sufficiently precise for ordinary easy curvature, the application of such a figure to the curves of 90′ radius on the New York Elevated road would mean a resistance due to curvature alone of about 34 pounds per ton. The curve resistance on these curves is far less than this figure. Although this is a very extreme case, it is a valuable check, since it shows the tendency of the increase of the resistance with an increase in the degree of the curve. This conclusion is also corroborated by the theoretical considerations already given, that the portion of the curvature resistance which is due to longitudinal slipping is absolutely independent of the radius. It is quite probable that the curvature resistance on sharp curves is also dependent on the velocity of the train, but, unfortunately, there is no experimental data by which such a conclusion can be definitely corroborated.

Searles makes an allowance of 0.448 pound per degree of curve per gross ton of 2240 pounds. He does not state the derivation of the value, nor how a value is obtained to the third significant figure, but, considering that such a value is the equivalent of precisely 0.4 pound per ton of 2000 pounds or a frictional coefficient of precisely .0002, it is possible that the apparently precise value may be based on a comparatively loose approximation.

119. Brake resistances.—The fact that grades may be so steep that they cannot be safely operated, when moving down the grade, without the use of brakes has been referred to in § 117. The energy consumed by brakes is hopelessly lost without any compensation. The kinetic energy possessed by the train is transformed into heat. All such energy is wasted and, in addition to this, a very considerable amount of steam is drawn from the boiler to operate the air-brakes which consume the power already developed. When trains are required to make frequent stops and yet maintain a high average speed, a considerable amount of power is consumed in applying the brakes. It has been demonstrated that engines, drawing trains in suburban service, making frequent stops and yet developing high speed between stops, will consume a very large proportion of the total power developed by the use of brakes. The brakes consume the power already developed and stored in the train as kinetic or potential energy, while the operation of the brakes requires additional steam-power from the engine. It should therefore not be forgotten that, in some kinds of service especially, the power required from the locomotive may be many times the amount of power which is required merely to overcome mere track and grade resistance.

120. Inertia resistance.—The two forms of train resistance, which, under some circumstances, are the greatest resistances to be overcome by the engine, are the grade and inertia resistances, and fortunately both of these resistances may be computed with mathematical precision. The problem may be stated as follows: What constant force P (in addition to the forces required to overcome the grade and various frictional resistances, etc.) will be required to impart to a body a velocity of v feet per second in a distance of s feet? The required number of foot-pounds of energy is evidently Ps. But this work imparts a kinetic energy which may be expressed by $\frac{Wv^2}{2g}$. Equating these values, we have $Ps=\frac{Wv^2}{2g}$, or

$$P=\frac{Wv^2}{2gs}. \qquad (2)$$

The force required to increase the velocity from v_1 to v_2 may likewise be stated as $P=\frac{W}{2gs}(v_2^2-v_1^2)$. Substituting in the formula the values $W=2000$ lbs. (one ton), $g=32.16$, and $s=5280$ feet (one mile), we have

$$P=.00588\ (v_2^2-v_1^2).$$

Multiplying by $(5280 \div 3600)^2$ to change the unit of velocity to miles per hour, we have

$$P=.01267\ (V_2^2-V_1^2).$$

But this formula must be modified on account of the rotative kinetic energy which must be imparted to the wheels of the cars. The precise additional percentage depends on the particular design of the cars and their loading, and also on the design of the locomotive. Consider, as an example, a box car, 60,000 lbs. capacity, weighing 33,000 lbs. The wheels have a diameter of 36″, and their radius of gyration is about 13″. Each wheel weighs 700 lbs. The rotative kinetic energy of each wheel is 4877 ft.-lbs. when the velocity is 20 miles per hour, and for the eight wheels it is 39,016 ft.-lbs. For greater precision (really needless) we may add 192 ft.-lbs. as the rotative kinetic energy of the axles. When the car is fully loaded (weight, 93,000 lbs.) the kinetic energy of translation for 20 miles per hour is 1,244,340 ft.-lbs.; when empty (weight, 33,000 lbs.) the energy is 441,540 ft.-lbs. The rotative kinetic energy thus adds (for this particular car) 3.15% (when the car is loaded) and 8.9% (when the car is empty) to the kinetic energy of translation. The kinetic energy which is similarly added, owing to the rotation of the wheels and axles of the locomotive, might be similarly computed. For one type of locomotive it has been computed to be about 8%. The variations in design, and particularly the fluctuations of loading, render useless any great precision in these computations. For a train of "empties" the figures would be high, probably 8 to 9%; for a fully loaded train it will not much exceed 3%. Wellington considered that 6% is a good average to use (actually used 6.14% for "ease of computation"), but considering (*a*) the increasing proportion of live load to dead load in modern car design, (*b*) the greater care now used to make up *full* train-loads, and (*c*) the fact that *full* train-loads are usually the critical loads, it would appear that 5% is a better average for the conditions of modern practice. Even this figure allows something for the higher percentage for the locomotive and something for a few empties in the train. Therefore, adding 5% to the coefficient in the above equation, we have the true equation

$$P = .0133(V_2^2 - V_1^2), \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which V_2 and V_1 are the higher and lower velocities respectively in *miles per hour*, and P is the force required *per ton* to impart that difference of velocity in a distance of *one mile*. If more convenient the formula may be used thus:

$$P_1 = \frac{70.224}{s}(V_2^2 - V_1^2), \quad . \quad . \quad . \quad . \quad (4)$$

in which s is the distance in feet and P_1 is the corresponding force.

As a numerical illustration, the force required per ton to impart a kinetic energy due to a velocity of 20 miles per hour in a distance of 1000 feet will equal

$$P_1 = \frac{70.224\,(400 - 0)}{1000} = 28 \text{ lbs.},$$

which is the equivalent (see § 117) of a 1.4% grade. Since the velocity enters the formula as V^2, while the distance enters only in the first power, it follows that it will require *four* times the force to produce twice the velocity in the same distance, or that with the *same* force it will require four times the distance to attain twice the velocity.

As another numerical illustration, if a train is to increase its speed from 15 to 60 miles per hour in a distance of 2000 feet, the force required (in addition to that required for all the other resistances) will be

$$P = \frac{70.224\,(3600 - 225)}{2000} = 118.50 \text{ lbs. per ton.}$$

This is equivalent to a 5.9% grade, and shows at once that it would be impossible, unless there were a very heavy down grade, or that the train was very light and the engine very powerful.

121. Train-resistance formulæ. — Train-resistance formulæ are usually empirical and are based on one of two forms:

$$\left.\begin{array}{l} R=c+fV, \\ R=c+fV^n \end{array}\right\} \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

in which R is the resistance per ton, f is a coefficient to be determined, V equals the velocity in miles per hour, and c is a constant also to be determined. Formulæ of the second class, which include some power of V represented by the exponent n, usually employ the second power, but there are some variations even from this. These formulæ disregard grade and curve resistances, inertia resistance, and the active resistance (or assistance) of the *wind* as distinct from mere atmospheric resistance. In short, they are supposed to give the resistance of a train moving at a uniform velocity over a straight and level track, there being no appreciable wind. It may readily be seen that, since grade and curvature resistances and the active pressure of the wind furnish resistances which are indefinitely variable, all general formulæ must necessarily ignore these elements. The quantity c represents those elements of resistance which are supposed to be constant, or so nearly constant that their variation with velocity may be ignored. The journal friction and the rolling friction are generally considered as belonging to this class. The velocity resistances are usually assumed to vary as the square of the velocity, and for such formulæ it only becomes necessary to determine the value of the coefficient f to obtain the value of this term. Very few resistance formulæ take any account of any variation in train-load, whether the cars are loaded or empty, and whether (in freight-trains) they consist entirely of box cars, of flat cars, or a combination of all kinds. It is well known that all these elements have a very material influence on the actual train resistance, so much so that a formula which ignores such influences must be considered as very approximate. Out of a great multitude of formulæ which have been proposed, a few have been selected for discussion, the formulæ having been modified (if necessary) to bring them to a uniform basis for comparison, in which case R equals the total resistance in pounds per ton of 2000 pounds.

(*a*) Baldwin Locomotive Works' formula:

$$R=3+\frac{V}{6}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

This formula has the merit of extreme simplicity, but since, as shown above, extreme simplicity is incompatible with accuracy, the most that can be claimed for such a formula is that it is approximately accurate for ordinary trains and for a considerable range of velocity. Evidently appreciating the fact that the formulæ is not applicable to high velocities, the following modification has been suggested for velocities between 47 and 77 miles per hour:

$$R=1.5+0.2V. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

(*b*) Wellington's formulæ. A very simple formulæ ascribed to Wellington is as follows:

$$R=4+0.0055V^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Although this formula is more simple than the formula immediately following, it is evidently impossible for it to be accurate for all conditions. Wellington devised a series of formulæ which should distinguish between the character of the loading, whether it was carried in box cars or flat cars, or whether the cars were loaded or empty. The formulæ also allow for the variation due to the weight of the train. Assuming that the constants have been properly chosen, these formulæ ought to give very much closer results than are obtainable by any other formula here quoted.

$$R = \left\{ \begin{array}{ll} 3.9 + .0065V + \dfrac{.57V}{W} & \text{. . . for loaded flat cars,} \\ 3.9 + .0075V + \dfrac{.64V}{W} & \text{. . . for loaded box cars,} \\ 6.0 + .0083V + \dfrac{.57V}{W} & \text{. . . for empty flat cars,} \\ 6.0 + .0106V + \dfrac{.64V}{W} & \text{. . . for empty box cars.} \end{array} \right\} \qquad (9)$$

It should, however, be noted that a train consisting partly of box cars and partly of flat cars will have a higher resistance than is shown by any of the above formulæ (and *not* a mean value), on account of the increased atmospheric resistance acting on the irregular form of the train.

(*c*) Barnes's formula:

$$R = 4 + 0.16V. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

It may be noted that Barnes's formula is identical with Wellington's simpler formula when the velocity is 29 miles per hour, but gives higher values for lower velocities and lower values for higher velocities.

(*d*) Aspinall's formula:

$$R = 2.23 + \frac{V^{\frac{5}{3}}}{56.9 + 0.0311L}. \quad . \quad . \quad . \quad . \qquad (11)$$

This formula declares that the resistance varies as the $\frac{3}{5}$ power of the velocity, and also inserts the extra term L, which denotes the length of the train in feet. This constitutes another method of allowing for the variation in the resistance due to the loading of the train. There is reason, however, to doubt the correctness of the form of this equation, since, if the train were comparatively long (as it might be with a train of empties), the denominator of that fraction would be increased, the fraction itself would be decreased, and the resistance per ton would be less. It is well known that the contrary would be the case, since of two trains with the same actual gross weight, one consisting of loaded cars and therefore comparatively short, and the other a comparatively long train of empty cars, the short train of loaded cars will have a less total resistance and therefore (in this case) a less resistance per ton. On the other hand, a long train will have a somewhat greater atmospheric resistance, although the difference will not be sufficient to compensate for the reduction in resistance due to heavy wheel-loads. As Aspinall's tests were made on the basis of English rolling-stock, their values are hardly applicable to American practice.

(*e*) Searles's formula:

$$R = 4.82 + 0.00536V^2 + \frac{0.00048V^2\,(\text{weight of engine and tender})^2}{\text{gross weight of train}}. \qquad (12)$$

This formula does not take account of differences in the form of the train (whether box cars or flats) which would affect the atmospheric resistance. Neither does it take into account the relation of length to weight, or whether the cars are loaded or empty. Considering as before two trains, one of which is short and heavily loaded, and the other a long train of empties, the weight of engine and tender and the gross weight of the train might be the same in both cases, and yet the resistance per ton for the train of empties would be considerably higher than for the train of loaded cars, although this formula gives them the same figure.

122. Comparison of the above formulæ.—For the purposes of comparison, we will compute the train resistance per ton according to the above formulæ for a locomotive weighing 130 tons and with 2043 tons behind the tender moving at the rate of seven miles per hour. The resistances would be as follows:

(*a*) Baldwin: $R=3+\frac{V}{6}=4.16.$

(*b*) Wellington: $R=4+.0055V^2=4.27.$

(*c*) Barnes: $R=4+.16V=5.12.$

(*d*) Aspinall: The formula is not strictly applicable, as before stated, but the comparison will be interesting. We will assume that the 2043 actual tons behind the tender, loaded two contents to one tare, consist of 44 cars. Assuming that the cars have a total length between coupler ends of 37 feet, the length of the train would be 1628 feet. Adding 62 feet for the engine, we would have $L=1690$ feet. The formula then becomes

$$R=2.23+\frac{25.6}{56.9+52.6}=2.23+.234=2.46.$$

(*e*) Searles: $R=4.82+0.262+0.183=5.265.$

Applying Wellington's more accurate formula, and assuming first that the cars were loaded box cars, we would have

$$R=3.9+0.367+0.014=4.28.$$

If the cars were loaded flat cars, the resistance would be

$$R=3.9+0.318+0.013=4.231.$$

It may be noted that these last two values agree fairly closely with Wellington's more general formula. The actual results obtained during Dennis's experiments were 4.7 pounds, which is a fair average between the low values given by Baldwin and Wellington and the higher values given by Barnes and Searles. The value given by Aspinall's formula is apparently inapplicable.

Comparing these formulæ for a fast passenger-train, the results will be given below. Assume that the train consists of six cars weighing 60,000 pounds each and that it is drawn by a locomotive whose total weight is 280,000 pounds. The train has a total length of 430 feet. We will compute, according to these formulæ, its resistance at 50 miles per hour.

(*a*) Baldwin, Eq. 7: $R=1.5+10=11.5$.
(*b*) Wellington: $R=4+13.75=17.75$.
(*c*) Barnes: $R=4+8=12$.
(*d*) Aspinall: $R=2.23+9.64=11.87$.
(*e*) Searles: $R=4.82+13.40+73.5=91.72$.

It may be noted that the first three formulæ agree about as closely as they did for the slow freight-train, and that even Aspinall's formula, although based on English practice, gives a result which is very close to the average. It is seen, however, that Searles's formula gives a result which is out of all proportion to the other results. Although the formula is stated by its author "to give the resistance per ton for all trains, whether freight or passenger, and at any velocity under ordinary circumstances," it is evidently inapplicable to the assumed case unless we admit that the other formulæ are worthless.

123. Dynamometer tests.—Tests to obtain the resistance of trains are usually made by placing a dynamometer car between the locomotive and the body of the train.

The coupler between the car and the locomotive includes a dynamometer attachment which automatically records at any instant the actual pull on the draw-bar. Apparently this ought to solve the problem very easily and accurately, but in practice it is found that the interpretation of the dynamometer records is not easy and is liable to misconstruction, unless care is taken to make several allowances. One of the practical difficulties in interpreting the results of dynamometer experiments is to determine the actual velocity, especially when the velocity is not regular. Speed-recorders are supposed to indicate the velocity at any instant, but they are not very accurate even when the velocity is uniform, and they are especially inaccurate when the velocity is fluctuating. When the velocity of the train is decreasing, the kinetic energy of the train is being turned into work, and a force transmitted through the dynamometer is less than the amount of the resistance which is actually being overcome. Therefore, unless the indication of the dynamometer is carefully corrected by adding to it the force calculated according to formula 4, which equals the force which is really assisting the train when its velocity is reduced from V_2 to V_1 in a distance s, the indication of the dynamometer will not represent the force required to overcome the resistances actually encountered by the train. On the other hand, when the velocity is increasing, the dynamometer indicates a larger force than is required to overcome the resistances, but the excess force is being stored up in the train as kinetic energy. In such a case, the force P_1, calculated from formula 4 on the basis of the differences of velocities in any assumed distance s, must be subtracted from the dynamometer record in order to obtain the force necessary to overcome the train resistances. Grade has a similar effect, and the force indicated by the dynamometer may be greater or less than that required at the given velocity on a level by the force which is derived from, or is turned into, potential energy. Since grade, either ascending or descending, is usually found in the track, the actual grade of the road-bed must be known and allowed for at all points. Curvature must likewise be allowed for, as it has a constant retarding force. Usually the allowance per ton is 0.5 pound.

CHAPTER XI.

MOMENTUM GRADES.

124. Velocity head.—When a train starts from rest and acquires its normal velocity, it overcomes not only the usual track resistances (and perhaps curve and grade resistances), but also performs work in accumulating a large amount of kinetic energy. Such work is not necessarily lost. In fact there need not be the loss of a single foot-pound of such energy, provided it is not necessary to dissipate the energy by the application of brakes. If for a moment we consider that a train runs without any friction, then, when running at a velocity of v feet per second, it possesses a kinetic energy which would raise it to a height of h feet, when $h=\frac{v^2}{2g}$, in which g is the acceleration of gravity which equals 32.16 feet per second in a second. Still ignoring friction, the train would climb a grade until it had attained an elevation of h feet above the point where its velocity was v. When it had climbed a height of h' feet (less than h) it would have a velocity $v_1=\sqrt{2g(h-h')}$. As an illustration assume that $v=30$ miles per hour $=44$ feet per second. Then $h=\frac{v^2}{2g}=30.1$ feet. Still assuming that there is no friction, the kinetic energy in the train would carry it up a grade until it had attained an elevation of 30.1 feet, or it would carry it for two miles up a grade of 15 feet per mile or half a mile up a grade of 60 feet per mile. When the train had climbed 20 feet there would still be 10.1 feet left of velocity head, and its velocity would be $v=\sqrt{2g(10.1)}=25.49$ feet per second $=17.4$ miles per hour. But these figures must be slightly modified, on account of the revolving-wheels, of the train, as already discussed in § 120. When train velocity is being acquired part of the work done is spent in imparting the energy of rotation to the driving-wheels and various truck-wheels of the train. Since these wheels run on the rails and must turn as the train moves, their rotative kinetic energy is just as effective (so far as it goes) in being transformed back into useful work. The proportion of this rotative energy to the kinetic energy of translation has already been computed in § 120, in which the corrective value of 5% has been adopted. Since v equals $\frac{5280}{3600}V=1.4667\,V$, in which v equals the velocity in feet per second and V equals the velocity in miles per hour, and since v^2 equals $2.151\,V^2$ we may write Velocity head

$$=\frac{v^2 \text{ in ft. per sec.}}{64.32}=\frac{2.151V^2 \text{ in m. per h.}}{64.32}=0.03344V^2$$

Adding 5% for the rotative kinetic energy of the wheels . . . . $=0.00167V^2$

The correct velocity head therefore . . . . $=0.03511V^2$

On account of the great usefulness of these values, as explained later, the velocity-head for velocities varying from 10 to 50 miles per hour have been computed as shown in Table XX. Part of these figures were obtained by interpolation, and the final hundredth may be in error by one unit, but it may readily be shown that the final hundredth is of no practical importance. It is also true that the chief use made of this table is with velocities much less than 50 miles per hour.

125. Practical use of Table XX.—The previous demonstration has been made under the assumption, many times repeated, that the frictional resistances to the movement of the train are zero. The same law will hold if we may assume that the engine is doing an amount of work which *at all times* is just equal to that required to overcome such resistances. It has been found that the tractive resistances (which here include all resistances except those due to grade) are nearly independent of velocity for a very considerable range of velocity, which includes the most common freight-train velocities. It is also assumed that the draw-bar pull is uniform for these various velocities. This last assumption is virtually the same as assuming that the tractive power of the drivers is independent of velocity, and that the engine is capable of varying its output measured in horse-power indefinitely. None of these assumptions are strictly true, but a thorough appreciation of this method of calculation will assist very materially in studying the value and use of momentum grades, since the error is practically inappreciable when operating small sags and humps, and does not become of very great value except in extreme cases. We will first apply the method to some practical cases on the basis, as before stated, that the tractive resistances are independent of velocity, and that the pull on the draw-bar of the locomotive is constant. Assume that a train is passing A (see Fig. 24) running at a velocity of 15 miles per hour. Assume that the throttle is not changed nor any brakes applied, and that the engine is capable of increasing its horse-power, so that, in spite of its increased velocity on the succeeding down grade, it is still able to exert the same draw-bar pull. At A its velocity head is that due to

TABLE XX.—VELOCITY HEAD (REPRESENTING THE KINETIC ENERGY) OF TRAINS MOVING AT VARIOUS VELOCITIES.

Velocity, m. per h.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	3.51	3.58	3.65	3.72	3.79	3.87	3.95	4.02	4.10	4.17
11	4.25	4.33	4.41	4.49	4.57	4.65	4.73	4.81	4.89	4.97
12	5.06	5.15	5.23	5.32	5.41	5.50	5.58	5.67	5.75	5.84
13	5.93	6.02	6.12	6.21	6.31	6.40	6.50	6.59	6.69	6.78
14	6.88	6.98	7.08	7.19	7.29	7.39	7.49	7.60	7.70	7.80
15	7.90	8.00	8.11	8.22	8.33	8.44	8.55	8.66	8.77	8.88
16	8.99	9.10	9.21	9.32	9.43	9.55	9.67	9.79	9.91	10.03
17	10.15	10.27	10.39	10.51	10.63	10.75	10.87	10.99	11.12	11.25
18	11.38	11.50	11.63	11.76	11.89	12.02	12.15	12.28	12.41	12.55
19	12.68	12.81	12.95	13.08	13.22	13.35	13.49	13.63	13.77	13.91
20	14.05	14.19	14.33	14.47	14.61	14.75	14.89	15.04	15.19	15.34
21	15.49	15.64	15.79	15.94	16.09	16.24	16.39	16.54	16.69	16.84
22	17.00	17.15	17.30	17.46	17.62	17.78	17.94	18.10	18.26	18.42
23	18.58	18.74	18.90	19.06	19.22	19.38	19.55	19.72	19.89	20.06
24	20.23	20.40	20.57	20.74	20.91	21.08	21.25	21.42	21.59	21.77
25	21.95	22.12	22.30	22.48	22.66	22.84	23.02	23.20	23.38	23.56
26	23.74	23.92	24.10	24.28	24.46	24.65	24.84	25.03	25.22	25.41
27	25.60	25.79	25.98	26.17	26.36	26.55	26.74	26.93	27.13	27.33
28	27.53	27.73	27.93	28.13	28.33	28.53	28.73	28.93	29.13	29.33
29	29.53	29.73	29.93	30.13	30.34	30.55	30.76	30.97	31.18	31.39
30	31.60	31.81	32.02	32.23	32.44	32.65	32.86	33.08	33.30	33.52
31	33.74	33.96	34.18	34.40	34.62	34.84	35.06	35.28	35.50	35.72
32	35.95	36.17	36.39	36.62	36.85	37.08	37.31	37.54	37.77	38.00
33	38.23	38.46	38.69	38.92	39.15	39.38	39.62	39.86	40.10	40.34
34	40.58	40.82	41.06	41.30	41.54	41.78	42.02	42.26	42.51	42.76
35	43.01	43.26	43.51	43.76	44.01	44.26	44.51	44.76	45.01	45.26
36	45.51	45.76	46.01	46.26	46.52	46.78	47.04	47.30	47.56	47.82
37	48.08	48.34	48.60	48.86	49.12	49.38	49.64	49.91	50.18	50.45
38	50.72	50.99	51.26	51.53	51.80	52.07	52.34	52.61	52.88	53.15
39	53.42	53.69	53.96	54.23	54.51	54.79	55.07	55.35	55.63	55.91
40	56.19	56.47	56.75	57.03	57.31	57.59	57.87	58.16	58.45	58.74
41	59.03	59.32	59.61	59.90	60.19	60.48	60.77	61.06	61.35	61.64
42	61.94	62.23	62.52	62.82	63.12	63.42	63.72	64.02	64.32	64.62
43	64.92	65.22	65.52	65.82	66.12	66.43	66.74	67.05	67.36	67.67
44	67.98	68.29	68.60	68.91	69.22	69.53	69.84	70.15	70.46	70.78
45	71.10	71.42	71.74	72.06	72.38	72.70	73.02	73.34	73.66	73.98
46	74.30	74.62	74.94	75.26	75.59	75.92	76.25	76.58	76.91	77.24
47	77.57	77.90	78.23	78.56	78.89	79.22	79.55	79.89	80.23	80.57
48	80.91	81.25	81.59	81.93	82.27	82.61	82.95	83.29	83.63	83.97
49	84.32	84.66	85.00	85.34	85.69	86.04	86.39	86.74	87.09	87.44
50	87.79	88.14	88.49	88.85	89.20	89.55	89.91	90.26	90.61	90.97

15 miles per hour or 7.90 feet. At *B* it has gained 20 feet more, and its velocity is that due to a velocity head of 27.90 feet, or nearly 28.2 miles per hour. Upon climbing the grade *BC*, when it reaches the point *B′*, it has given up its velocity head, due to the additional 20 feet, and its velocity head is again 7.90. At the point *C*, which is 4 feet higher than *B′*, its velocity head is only 3.90, which corresponds to a speed of about 10.5 miles per hour. As the train starts down the grade *CD* its velocity continues to increase from 10.5 miles per hour, and when it has reached *C′* it has again recovered the 4 feet of velocity head and will again be moving at the velocity of 15 miles per hour. If at this point the grade again becomes level, the train will continue to move on as before at a velocity of 15 miles per hour. It will have been practically uninfluenced by the presence of the combined sag and hump.

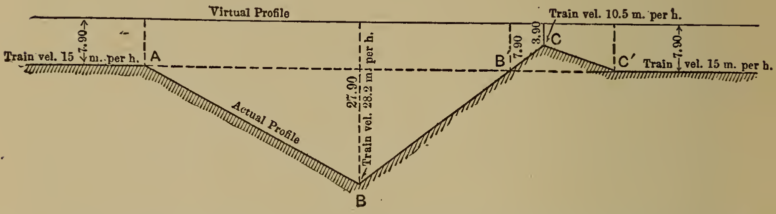


FIG. 24.—Relation of virtual and actual profile through a sag and over a hump.

126. Accuracy of the above statement.—The late A. M. Wellington, in giving a detailed solution of a problem substantially like the above, declared that he had taken velocity and dynamometer records in hundreds of cases of trains that were operated substantially as above, and that he had found that for all practical purposes the drawbar pull was constant, whether the velocity was great or small, and that the velocity at the foot of the sag or at the summit of the hump was substantially in accordance with the theoretical figures obtained for the particular case. In a paper read before the American Society of Civil Engineers on December 3, 1902, by Mr. A. C. Dennis, the statement was made that, as a result of tests aggregating thousands of miles of train operation, he found that freight-train resistance, when duly corrected for existing curvature and grade and for change in velocity, was substantially a uniform quantity at about 4.7 pounds per ton for loaded trains between the velocities of 7 and 35 miles per hour. Since the velocities in the above example are well within these limits, there would be little or no error due to variation of tractive resistances. Assume that the train in the above problem weighs 1500 tons. Let us assume that it approached the point *A* on a level track, and that it was moving at a velocity of 15 miles per hour, which is at the rate of 22 feet per second. Assuming that the tractive resistance is 4.7 pounds per ton, we would have, as the total horse-power developed at the speed of 15 miles per hour,

$$\frac{1500 \times 4.7 \times 22}{550} = 282 \text{ H.P.}$$

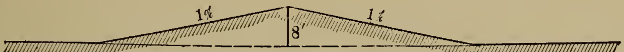
According to the assumption of a uniform draw-bar pull, when the train reached the bottom of the sag it would be moving at a velocity of 28.2 miles per hour, and it must therefore be developing 530 H.P. When it has moved up the succeeding grade and has reached the summit of the hump, the velocity is assumed to be 10.5 miles per hour instead of 15, and the horse-power required at this velocity will be only 197.4. Although the horse-power developed by a locomotive may vary between rather wide limits, the range of this variation is subject to definite limitations. At a very low velocity the tractive power is absolutely limited by the frictional resistance between the driving-wheels and the rails. Although the coefficient of friction will not ordinarily exceed 25%, there are some cases where, by the use of sand, a coefficient approximating one-third may be obtained. Therefore the weight on the drivers multiplied by 25% is usually a limiting measure of the tractive power of the locomotive. At very low velocities the maximum horse-power of the locomotive is therefore limited by the product of the maximum tractive power and the velocity which the locomotive can develop. At some speed, which is usually over 10 to 15 miles per hour, it not only becomes impossible for the locomotive to develop steam fast enough to supply the cylinders at full stroke, but it also becomes far more effective to use the steam expansively. The maximum tractive force which can be developed by an engine for one complete revolution of a driver equals

Theoretical tractive force

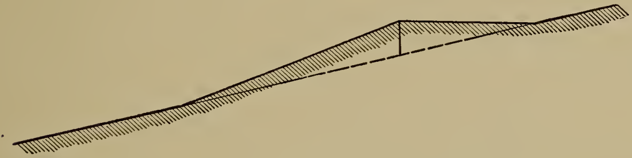
$$= \frac{(\text{diam. piston}) \times \text{av. steam-pr.} \times \text{stroke}}{\text{diameter of drivers}}. \quad (13)$$

The effective steam-pressure is considerably less than this, and none of the above quantities are variable except the pressure. If the effective steam-pressure in the cylinder is reduced, as must be the case when the steam is used expansively, then the effective tractive power is unquestionably reduced. In spite of the reduction in effective steam-pressure, it is possible that the speed may become so high that the horse-power developed is greater, in spite of the reduced draw-bar power, than it was before. Nevertheless, the draw-bar pull certainly does decrease with increased velocity. The speed at which it will begin to decrease depends on the ability of the boiler to develop steam rapidly. In Fig. 26 is shown in a diagram the reduction in tractive power with increase of velocity of the consolidation locomotive with which Mr. A. C. Dennis made the tests above referred to. It will be noticed in this particular case that the draw-bar pull commenced to decrease immediately, and that at 14 miles per hour the tractive force had reduced to 75%.

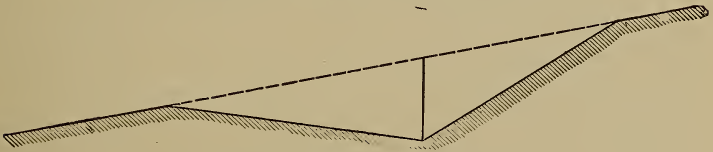
127. Utilization of Table XX.—Locomotive engineers very soon learned to utilize the advantage of "a run at the hill," and found that whenever they were able to approach a hill with a high velocity they would be able to draw up that hill a considerably heavier train than could be hauled if they started from rest or at a low velocity at the bottom of the hill. This advantage, however, is limited by the length of the hill, and it really becomes a question of the difference of elevation which can be surmounted by virtue of the kinetic energy stored in the train when it reaches the bottom of the hill. As the train climbs the hill and its velocity diminishes, the tractive force will increase rather than diminish, the tractive resistance will diminish rather than increase (assuming that



(*a*) Hump in track otherwise level.



(*b*) Hump on a grade otherwise uniform.



(*c*) Sag on a grade otherwise uniform.

Fig. 25.—Sags and humps on grades otherwise uniform.

the velocity does not decrease to less than 7 miles per hour), and therefore the kinetic energy can all be utilized in overcoming the elevation. About the only exception to this occurs when a freight-train has been forced to attain such a high velocity at the bottom of a hill that the reserve boiler-power has been overtaxed, and the boiler-pressure falls because the boiler is unable to produce steam with sufficient rapidity, but this will be largely a matter of the way the engine is handled. In a very simple case, such as the mere insertion of a hump either on an otherwise level track or on an otherwise uniform grade, such as is illustrated in Fig. 25 (*a*) or (*b*), whenever we can rely on a train reaching that hump with a sufficient velocity, and with the engine doing an amount of work which would carry it along the *uniform* grade at that velocity, Table XX will show whether that hump can be surmounted so that the velocity at the summit of the hump will still be within practicable limits, say 10 miles per hour. The other case (*c*) in Fig. 25 cannot always be determined accurately by this table, although the table may be depended on to give an approximate result, unless the case is very extreme. If a sag is very deep, one of several things may happen. First, the velocity at or near the bottom of the sag may become so great that steam must be shut off and brakes applied in order to prevent the train from attaining an objectionably high velocity. In such cases the table is not supposed to apply, since an express condition of the table is that the tractive force exerted by the engine is uniform. Second, even if it is attempted to operate the engine so that the tractive force is uniform, it may become impossible, as explained above, for the boiler to make steam fast enough to develop such power. If that full amount of power is not developed at the bottom of the sag, then the full amount of kinetic energy will not be developed, which will be necessary to permit the train to surmount the steeper grade and reach the upper end of the sag with its original velocity. Whether this will be the case can best be determined by means of momentum diagrams, such as will be described later.

Momentum Diagrams and Tonnage Ratings.

128. Tonnage rating.—The following demonstration is based very largely on the admirable paper by Mr. A. C. Dennis, M. Am. Soc. C. E., which has been previously referred to. The paper as originally presented is very much condensed, and is not easy to be understood by those who have little or no knowledge of the subject. The statements and numerical illustrations have therefore been amplified in the endeavor to present a somewhat difficult subject in a simple form.

129. Tonnage rating of locomotives.—Dennis's experiments indicated that the draw-bar pull of the particular locomotive tested, after being corrected for inertia, grade, and curvature, when drawing a train of empty box cars, averaged about 8.9 pounds per ton. The variation from this figure between the velocities of 7 and 30 miles per hour did not exceed 0.1 pound per ton. On the other hand, the tractive resistance to loaded cars was very uniform at 4.7 pounds per ton when the "tare-weight," or weight of the empty cars, was one-third of the total weight. Since train-loads are made up of loaded, partially loaded, and empty cars, the only practicable method of uniform tonnage rating is to equate live load and tare-weight to a uniform basis of resistance. Since empty cars showed a resistance of 8.9 pounds per ton, and since the resistance *per ton* was lowered to 4.7 when the cars were loaded with a live load twice the tare-weight, we may write an equation as follows, in which R = the resistance in pounsd per ton due to the *live load,*

$$R\times\tfrac{2}{3}+8.9\times\tfrac{1}{3}=4.7,$$

from which we may derive $R=2.6$. The reasonableness of this view becomes more apparent when we consider that the total tractive resistance consists of the summation of several resistances, some of which (such as atmospheric resistance) are independent of weight, and some of which (such as axle resistance) are *decreased per ton* by an increase in weight.

According to the above figures, a 50-car train of empties, weighing 15 tons each, would have a tractive resistance of $50\times15\times8.9=6675$ pounds. If each car was loaded with 15 tons, we would have an additional tractive resistance of

$$50\times15\times2.6=1950 \text{ pounds},$$

or a total of 8625 pounds. Loading on 15 more tons per car would add another 1950 pounds, making a total of 10,575 pounds. But the total tonnage would then be 2250 and the average resistance would be 4.7 pounds per ton. The tonnage rating is then given by multiplying the tare-weight by a factor such that the "rating ton," as it is called, multiplied by 2.6 will equal the actual tare-weight resistance per ton. But since the grade resistance per ton is a definite quantity, we cannot use the increased hypothetical equivalent in tons in allowing for the actual grade resistance. This factor therefore depends on the rate of grade. For example, on a 0.4% grade the tractive resistance for a "rating ton" is 2.6 pounds; the grade resistance is 8 pounds, the total is 10.6. A ton of tare has a resistance of 9.0 and has a grade resistance of 8.0, or a total of 17. This is 160% of a rating ton. The corresponding figures for other grades are as given in Table XXI.

In Fig. 26 is shown the actual tractive power of the

TABLE XXI.—RATIO OF TARE TONS TO RATING TONS FOR VARIOUS GRADES.

Grade in per cent.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$\frac{\text{Tare ton}}{\text{Rating ton}}$	346%	239%	197%	174%	160%	151%	144%	139%	134%	131%	128%

Grade in per cent.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
$\frac{\text{Tare ton}}{\text{Rating ton}}$..	128%	126%	124%	123%	121%	120%	118%	117%	117%	116%	115%

locomotive used in Mr. Dennis's tests. The curve of tractive power was obtained by adding to the actual dynamometer pull the grade and rolling resistance of the locomotive and tender. The curve represents average values; the maximum values were about 1000 pounds higher.

130. Tonnage rating for a given grade and velocity.—We will first compute the tonnage rating for this locomotive on the basis of a velocity of 7 miles per hour and for a 0.4% grade. The tractive power, as obtained from Fig. 26, for this speed is 28,200 pounds. The grade and tractive resistance for a rating ton on this grade is $(8.0+2.6)$ or 10.6 pounds per ton. At 7 miles per hour, the locomotive could therefore handle $(28{,}200 \div 10.6)$ or 2660 gross rating tons. The actual weight of the locomotive and tender was 130 tons. On a 0.4% grade this is the equivalent of $(160\% \times 130) = 208$ rating tons, which leaves 2452 rating tons behind the tender. The actual load behind the tender will depend on the character of the car loading. Assume first that all cars were empty, then the actual loading would be $2452 \div 1.60 = 1529$ tons. If the live load exactly equaled the tare, we would have for each two tons one ton of live load and (1×1.60) rating tons of tare. The actual tonnage would be $\frac{2}{1+1.60} \times 2452 = 1886$

tons. If the live load is twice the tare, the actual tonnage would be $\frac{3}{2+1.60}\times 2452=2043$ tons. The above calculations are on the basis of 7 miles per hour. If the speed were increased to 25 miles per hour, the tractive power

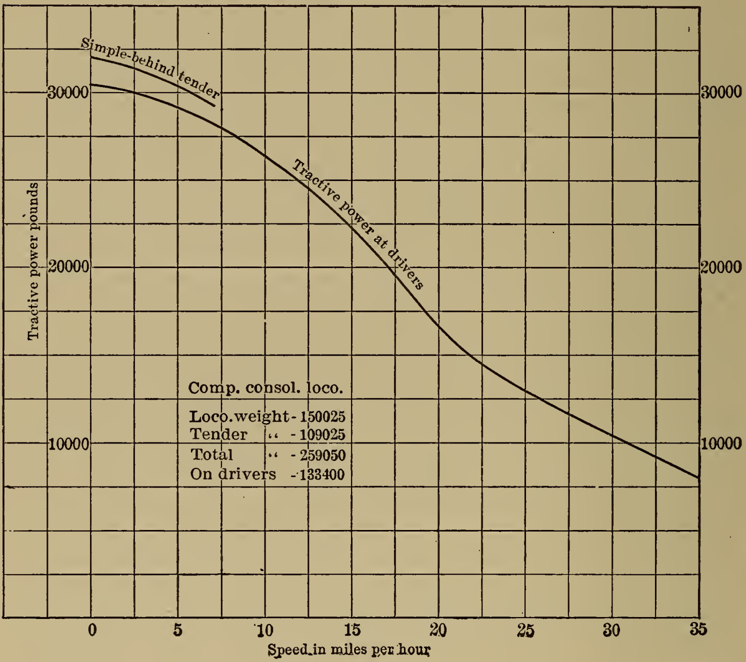


FIG. 26.—Locomotive tractive power curve.

of the locomotive is considerably less. According to Fig. 26 it is only 12,900 pounds. Dividing this as before by 10.6 we have 1217 rating tons. Subtracting the 280 rating tons for the locomotive and tender, we have left 1009 rating tons for the cars. As before, we would have

$$1009 \times \frac{2}{1+1.60} = 776 \text{ tons for half loading,}$$

$$1009 \times \frac{3}{2+1.60} = 842 \text{ '' '' full ''}$$

and $$1009 \div 1.60 = 631 \text{ '' '' empties.}$$

A tabulation of the above values will more clearly indicate the comparative effect of grades and loading. It is assumed that "full load" means a live load of *double* the weight of the car.

Velocity of train.	Cars empty.	Half loaded.	Fully loaded.
7 miles per hour.	1529	1886	2043
25 " " "	631	776	842

The reduction in the capacity of the locomotive at the higher speed is not due to the extra resistance, but to the inability of the locomotive to develop the requisite power at the higher rate.

131. Acceleration curves.—If we divide the total tractive power by the gross rating tonnage, we will have the available power in pounds per ton. If we subtract from this the tractive resistances, including grade resistance and the resistance due to curvature, the remainder will be the force which is available for acceleration. If these resistances are more than the available power per ton, the difference will be negative and will indicate a retarding force.

On the same principle as used in computing gravity resistance (§ 117), we may say that a given accelerative force per ton will be able to alter the potential head (or velocity head) by a proportional amount in a given distance. If P = the accelerating force per ton, then

$$P : 2000 :: (h_2 - h_1) : s,$$

in which h_2 and h_1 are the two velocity heads and s the distance. If we say that $h=0.03511V^2$ (see § 121), and substitute for V_1 and V_2 in Eq. 4 (§ 120) the values $\frac{h_1}{03511}$ and $\frac{h_2}{.03511}$, we will have

$$P=\frac{2000}{s}(h_2-h_1), \quad \text{or} \quad s=\frac{2000}{P}(h_2-h_1), \quad . \quad (14)$$

which is the same as the above equation. If our accelerating force is, say, 10 pounds per ton, then the distance required for a change of one foot of velocity head will be $\frac{2000}{10}$ or 200 feet.

Assume that the consolidation locomotive which we have been discussing is loaded with a train-load of 2452 rating tons behind the tender, which is the capacity of that locomotive running for an indefinite distance at 7 miles per hour up a 0.4% grade. This loading (2452 rating tons) might be made up of an indefinite number of combinations of empty cars, loaded cars, or loaded and empty cars. The train having been started out from the terminal with this loading, we wish to compute its probable behavior on other grades and at different velocities. We will first study its behavior on a level grade. Since it is working in a manner which would carry the train up a 0.4% grade at 7 miles per hour, it will evidently gain velocity on the level grade. The total weight of train and engine is 2660 rating tons, on which the resistance due to traction is only $2660\times2.6=6916$ pounds. The tractive power of this engine at various velocities is as shown in the diagram Fig. 26. The tractive power for each velocity in miles per hour is as given in Table XXII. For example, at 10 miles per hour the tractive power is 26,400 pounds. Subtracting from this the power required for tractive resistance, which we will call 6900 for a round number, we will have 19,500 pounds available for acceleration. The velocity head at 10 miles per hour (as taken from Table XXII) is 3.51; for 9 miles per hour it is 2.84. The difference is .67 foot. The total weight of our train in rating *pounds* equals 5,320,000. Therefore the distance required to increase the velocity from 9 to 10 miles per hour equals (see Eq. 6)

$$s=\frac{5,320,000}{19,500}\times .67=183,$$

which means that the tractive power of the engine is such that it would increase the velocity of that train from 9 to 10 miles per hour in a distance of 183 feet. This figure, 183, is found in Table XXII in column 6, opposite the velocity of 10 miles per hour in column 1. The other numbers of column 6 are similarly obtained. The numbers of column 7 are obtained in each case by adding the sum of all the distances from zero, as given in column 6, and give the total distance from the origin that must be traveled before the locomotive working in that manner will attain the velocity as given in column 1. Considering the numbers in column 7 as ordinates, we may plot the acceleration curve marked "level" in Fig. 27.

To determine the behavior of this train on other grades, we will apply this same method to determine the other acceleration curves as given in Fig. 27. For example, the tractive power required of the locomotive at 7 miles per hour on a 0.4% grade is 28,200 pounds. At 5 miles per hour the tractive power of the engine is 29,100 pounds, and therefore the surplus is only 900 pounds (as given in column 8). The distance required for the difference of velocity head between 4 and 5 miles per hour, computed as before, equals about 1890 feet. Working out the

FIG. 27.—Diagram showing distances for various changes in velocity on grades shown for consolidation locomotive working compound and hauling full rating for 0.4% grade, compensated.

other distances similarly, we would have the other numbers in column 9, and adding these partial distances we have the sum totals as given in column 10. It should be remembered, however, that this curve has but little value, since the computations depend on the assumption of a uniform resistance per ton, which is far from being true with *very low* velocities. The form of the curve, however, is very instructive, since it shows that when it is running up the 4% grade with a velocity less than 7 miles per hour its surplus accelerative power is very small; it must necessarily run a long distance before its velocity will materially increase, and theoretically it will require an infinite time to quite reach the velocity of 7 miles per hour. Speaking mathematically, the curve (+0.4) is asymptotic to the vertical line over 7.

In Table XXII the ordinates for the lowest of the acceleration curves (−1.0) has been worked out in columns 11, 12, and 13. In this case each rating ton assists the tractive power by a force of (20.0−2.6), or 17.4 pounds per ton. This makes a total added power of 46,284 pounds, which we call 46,300 for round numbers. Adding this constant to the tractive power of the locomotive, we have the net tractive power available for acceleration as shown in column 11. Applying these values similarly, we obtain the comparative short distances required to change the velocity heads by the amounts given in column 4, and in column 13 we have the total distance required to attain the given velocities.

132. Retardation curves.—When the train has succeeded in acquiring a high velocity on a favorable down grade and then strikes an up grade, it will be unable to maintain that high velocity, and its velocity will gradually decrease. The distance required for the decrease from one velocity to another will be as given by the retardation curves shown in Figs. 27, 28, and 29. For example, if the train has

TABLE XXII.—DETERMINATION OF COÖRDINATES OF VELOCITY-DISTANCE CURVES FOR ONE TYPE OF LOCOMOTIVE.

Velocity, m. per h.	Tractive power, pounds.	Velocity head.	Difference of Velocity heads	Operating on level.			Operating on +0.4% grade.			Operating on −1.0% grade.		
				Surplus power over 6900 pounds.	Diff. in distance for velocity heads.	Total distance.	Surplus power over 28,200 pounds.	Diff. in distance for velocity heads.	Total distance.	Net tractive power, 46,-300 pounds.	Diff. in dist. for vel. heads.	Total distance.
1	2	3	4	5	6	7	8	9	10	11	12	13
1	30,300	.03	0.035	23,400	8	8	2,100	90	90	76,600	2	2
2	30,000	.14	.105	23,100	24	32	1,800	310	400	76,300	7	9
3	29,800	.32	.18	22,900	42	74	1,600	600	1,000	76,100	13	22
4	29,500	.56	.24	22,600	56	130	1,300	980	1,980	75,800	17	39
5	29,100	.88	.32	22,200	77	207	900	1,890	3,870	75,400	23	62
6	28,700	1.26	.38	21,800	91	298	500	4,040	8,910	75,000	27	89
7	28,200	1.72	.46	21,300	115	413				74,500	33	122
8	27,600	2.25	.53	20,700	136	549				73,900	38	160
9	27,000	2.84	.59	20,100	156	705				73,300	43	203
10	26,400	3.51	.67	19,500	183	888				72,700	49	252
11	25,700	4.25	.74	18,800	209	1,097				72,000	55	307
12	24,900	5.06	.81	18,000	239	1,336				71,200	60	367
13	24,000	5.93	.87	17,100	270	1,606				70,300	66	433
14	23,100	6.88	.95	16,200	312	1,918				69,400	73	506
15	22,200	7.90	1.02	15,300	355	2,273				68,500	79	585
16	21,200	8.99	1.09	14,300	405	2,678				67,500	86	671
17	20,100	10.15	1.16	13,200	467	3,145				66,400	93	764
18	19,000	11.38	1.23	12,100	541	3,686				65,300	100	864
19	17,900	12.68	1.30	11,000	628	4,314				64,200	108	972
20	16,800	14.05	1.37	9,900	737	5,051				63,100	115	1,087
21	15,700	15.49	1.44	8,800	870	5,921				62,000	123	1,210
22	14,900	17.00	1.51	8,000	1,004	6,925				61,200	131	1.341
23	14,100	18.53	1.58	7,200	1,167	8,092				60,400	139	1,480
24	13,400	20.23	1.65	6,500	1,350	9,442				59,700	147	1,627
25	12,900	21.95	1.72	6,000	1,524	10,966				59,200	154	1,781
26	12,400	23.74	1.79	5,500	1,730	12,696				58,700	162	1,943
27	11,900	25.60	1.86	5,000	1,979	14,675				58,200	170	2,113
28	11,400	27.53	1.93							57,700	178	2,291
29	10,900	29.53	2.00							57,200	186	2,477
30	10,400	31.60	2.07							56,700	194	2,671

somehow acquired a velocity of 30 miles per hour, the tractive power of that engine at that velocity is 10,400 pounds. Assume that it then strikes a +0.4% grade. The tractive resistance per rating ton is 8.0+2.6, or 10.6 pounds per ton. The tractive force required is therefore 28,200 pounds. The deficit at this velocity is 17,800 pounds, which must be considered as a retarding force.

As before, since the difference of velocity heads for 29 and 30 miles per hour equals 2.07 feet, the distance

$$s=\frac{5,320,000}{17,800}\times 2.07=619.$$

This gives the point on the +0.4% retardation curve in the ordinate over 29 miles per hour. The numerical work of computing all of these values for one curve can best be accomplished by a series of three columns, such as columns 5, 6, and 7 in Table XXII, following the preliminary set of columns from 1 to 4. Each retardation curve will require a similar set of columns. Figs. 27, 28, and 29 are copies of the diagrams prepared by Mr. A. C. Dennis in illustrating the article above referred to. It will be found that the distances given in columns 7, 10, and 13 of Table XXII agree substantially with the value of the ordinates given in these diagrams. Such discrepancies as do exist are due to the fact that the tractive power of the engine has been measured *to scale* from the diagram Fig. 26, which indicates the tractive power.

133. Practical utilization of these diagrams.—Borrowing the example given by Mr. Dennis, assume that our locomotive has been loaded with 2452 rating tons behind the engine, which is the requirement for a +0.4% grade at 7 miles per hour. Suppose that a start has been made on a level grade 5000 feet long, followed by 4000 feet of 6.0% grade, followed by 3000 feet of −0.2% grade. Since the train starts on a level and is loaded on the basis of a +0.4% grade, we must follow its course for 5000 feet on the acceleration curve marked "level" in the diagram of Fig. 27. This curve has an ordinate corresponding to 5000 feet when the train is moving at a velocity of 20 miles per hour. This is therefore the velocity of the train when it strikes the +0.6% grade. The course of the

FIG. 28.—Diagram showing distances for various changes in velocity on grades shown for consolidation locomotive working compound and hauling full rating for 0.5% grade, compensated.

train must then be studied from the retardation curve for 0.6%. This curve has an ordinate of 3600 on the 20 miles per hour line. Incidentally we may remark that if this train had started from any point with a velocity of 30 miles per hour up this grade, its velocity would have dropped to 20 miles per hour in 3600 feet. 4000 feet further gives us 7600 feet. The point on this curve which has an ordinate of 7600 feet occurs at about 8 miles per hour. The train then passes the summit at this velocity and starts on a −0.2% grade, which will evidently be an acceleration curve. Eight miles per hour on this grade corresponds to about 400 feet. Adding 3000 we have 3400 feet, which on this curve corresponds to a velocity of nearly 21½ miles per hour.

The only apparent difficulty in the above demonstration is the fact that, when the train is starting, the resistance is far higher than the resistance which has been found to be so uniform at velocities above 7 miles per hour. Whether this would be compensated by the fact that at very slow velocities the tractive force may be largely increased by the use of sand is not very certain. Mr. Dennis's diagram showing the tractive force at velocities but little above zero do not show any marked increase in the tractive force at very low velocities. The above method cannot be considered as precise, except on the basis that at very low velocities the resistance is no greater than at somewhat higher velocities, which is certainly not the case. These diagrams are probably very reliable for *variations* of freight-train velocities between 7 and 30 miles per hour. They are useful in obtaining the behavior of a train through a sag or over a hump. They are probably not so reliable when considering the movement of a train which starts from rest. In the numerical case just considered the velocity of the train at the end of the level grade of 5000 feet would probably be less than 20 miles

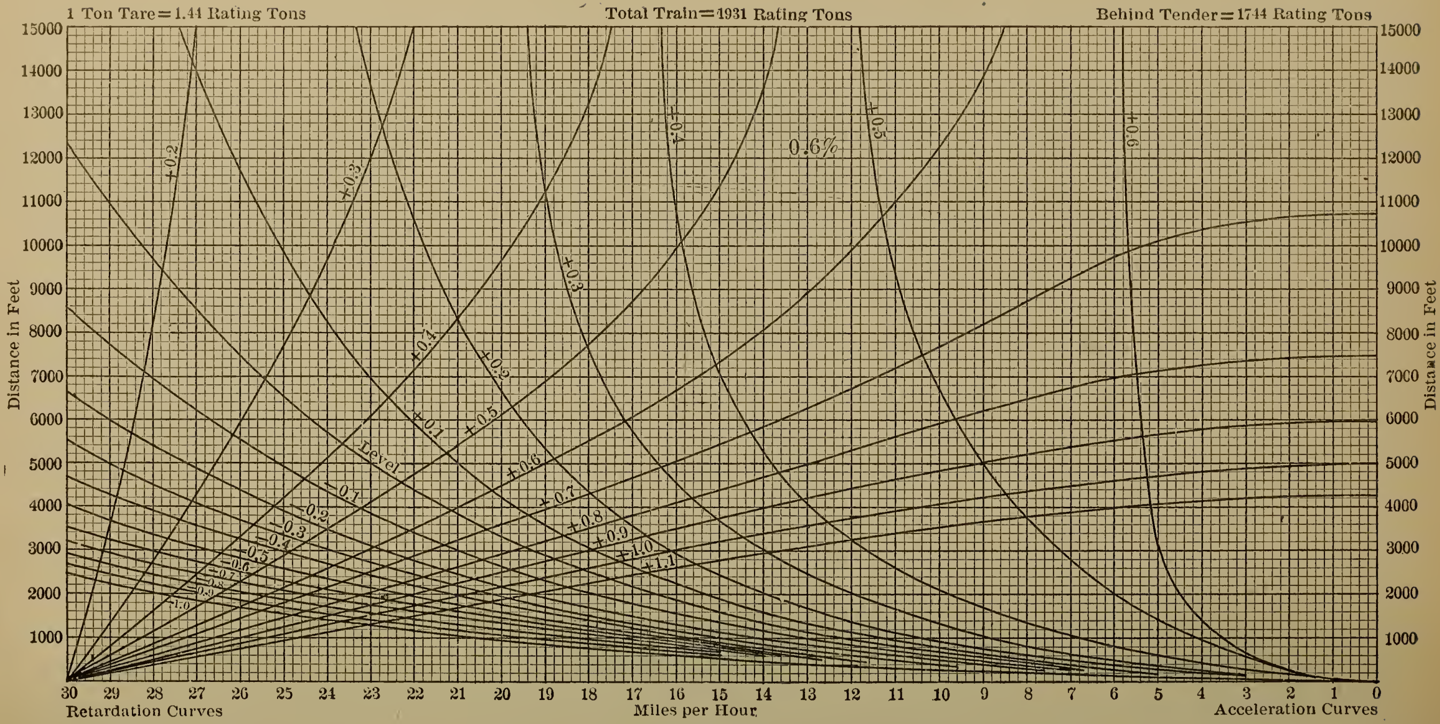


FIG. 29.— Diagram showing distances for various changes in velocity on grades shown for consolidation locomotive working compound and hauling full rating for 0.6% grade, compensated.

per hour, since the resistance at starting would be considerably greater. If, however, it had somehow acquired that velocity of 20 miles per hour at the beginning of the +0.6% grade, its behavior over that grade and down the following grade would certainly be about as computed.

134. Another tonnage-rating formula (Henderson). — The following formula has been proposed by Mr. G. R. Henderson, and has the merit of great simplicity combined with practical agreement with the more complicated formulæ based on elaborate tests.

Let R = the resistance of the train or the pull at the tender draw-bar in pounds;
T = the number of tons back of the tender, including cars and contents;
C = the number of cars in the train;
P = rate of grade in per cent.

For speeds up to 12 miles per hour

$$R = T\,(3.5 + 20P) + 50C.$$

Applying this formula to a numerical case, let us assume three trains, one a train of empties, the second half filled, and the third of full cars, a full load being assumed as twice the weight of the car. The first train has 45 empties, each weighing 20 tons; the second train has 28 cars, each weighing 20 tons and carrying 20 tons of freight; the third train has 20 cars, each weighing 20 tons and carrying 40 tons of freight. Then the draw-bar pulls *on a level* would be as follows:

$$\begin{aligned}
R &= (900 \times 3.5) + (50 \times 45) = 5400,\\
R &= (1120 \times 3.5) + (50 \times 28) = 5320,\\
R &= (1200 \times 3.5) + (50 \times 20) = 5200.
\end{aligned}$$

The resistances *per ton* are 6, 4.75, and 4.33 respectively.

It may be noted that the above values per ton are not as high for empty cars as those given by Mr. Dennis's tests, although the values for loaded cars agree fairly well.

PART III.

PHYSICAL ELEMENTS OF THE PROBLEM.

CHAPTER XII.

DISTANCE.

135. Relation of distance to rates and expenses.—Rates are usually based on distance traveled, on the apparent hypotheses that each additional mile of distance adds its proportional amount not only to the service rendered but also to the expense of rendering it. Neither hypothesis is true. The value of the service of transporting a passenger or a ton of freight from *A* to *B* is a more or less uncertain gross amount, depending on the necessities of the case and independent of the exact distance. Except for that very small part of passenger traffic which is undertaken for the mere pleasure of traveling, the general object to be attained in either passenger or freight traffic is the transportation from *A* to *B*, however it is attained. A mile greater distance does not improve the service rendered; in fact it consumes valuable time of the passengers and delays and perhaps deteriorates the freight. From the standpoint of service rendered, the railroad which adopts a more costly construction, and thereby saves a mile or more in the route between two places, is thereby fairly entitled to additional compensation rather than have it cut down, as it would be by a strict mileage-rate. The actual value to a passenger of being transported from New York to Philadelphia depends on his individual requirements, which may vary from a mere whim to the most imperative necessity. In one case the money value approaches zero; at the other extreme, money could hardly measure the loss if the trip were impossible. If the passenger charge between New York and Philadelphia were raised to $5, $10, or even $20, there would still be some passengers who would pay it and go, because to them it would be worth $5, $10, or $20, or even more. Therefore, when they pay $2.50 they are not necessarily paying what the service is worth to them. The service rendered cannot therefore be made a measure of the charge, nor is the service rendered proportional to the miles of distance.

The idea that the cost of transportation is proportional to the distance is much more prevalent and is in some respects more justifiable, but it is still far from true. This is especially true of passenger service. The extra cost of transporting a single passenger is but little more than the cost of printing his ticket. Once aboard the train, it makes but little difference to the railroad whether he travels one mile or a hundred. Of course there are certain very large expenses due to the passenger traffic which must be paid for by a tariff which is rightfully demanded, but such expenses have but little relation to the cost of an additional mile or so of distance inserted between stations. The same is true to a slightly less degree of the freight traffic. As shown later, the items of expense in the total cost of a train-mile, which are directly affected by a small increase in distance, are but a small proportion of the total cost.

136. The conditions other than distance that affect the cost; reasons why rates are usually based on distance.—Curvature and minor grades have a considerable influence on the cost of transportation, as will be shown in detail in the succeeding chapters, but they are never considered in making rates. Ruling grades have a very large influence on the cost, but they are likewise disregarded in making rates. An accurate measure of the effect of these elements is difficult and complicated, and would not be appreciated by the general public. Mere distance is easily calculated; and the railroads therefore adopt a tariff which pays expenses and profits, even though the charges are not in accordance with the expenses or the service rendered.

An addition to the length of the line may (and generally does) involve curvature and grade as well as added distance. In this chapter is considered merely the effect of the added distance. The effect of grade and curvature must be considered separately, according to the methods outlined in succeeding chapters. The additional length considered is likewise assumed *not* to affect the business done nor the number of stations, but that it is a mere addition to length of track.

137. Variable effect on expenses of extent of change in distance.—It will be developed later that the actual added expense of increasing the length of the line will depend very largely on the amount of that increase. An engineer frequently has occasion to make a slight change in the alinement which may make a difference in the length of the line at that place of a very few feet. It is demonstrable that certain items in the expense of operation will be absolutely unaffected by such a change, while other expenses will be increased nearly, if not quite, in their full proportion. On the other hand, if the change of line amounts to several miles, a very much larger proportion of the expenses will be increased in their full proportion. If the question of substituting an entirely different location on a division of approximately 100 miles was being considered, then, so far as distance itself was concerned (ignoring for the moment the question of curvature, grades, etc., which must be considered separately), the expenses of transporting freight over either of those two lines would be more nearly proportional to the exact mileage. This phase of the question will be considered in detail later on.

Effect of Distance on Operating Expenses.

138. Effect of changes in distance on maintenance of way.—The items of maintenance of way are more nearly affected in proportion to the distance than any other group of items. In fact it will be easier to note the exceptions or to estimate the discount from 100%, which should be estimated as the additional charge for each subitem. The cost of track-labor, which is such a large percentage of the total cost of Item 1 (see Table IX in Chapter VI), and even of the whole group of maintenance-of-way expenses, will vary almost exactly in accordance with the distance. If the track-labor was so perfectly organized that there were no more laborers than could precisely accomplish the necessary work, working full time, then any additional labor would necessarily require a greater expenditure for laborers. Although a division of a road is divided into sections of such a length that a gang of say six or seven men will be employed as steadily as possible in maintaining the track in proper condition, the addition of a few feet of track would not probably have the effect of increasing the number of sections, nor would it even require the addition of another man to the track-gang. It might require a little harder work in maintaining a section, it *might* even mean a slight lowering in the standard of work done in order that the whole section should be covered. The fact remains that the cost of track-labor will not inevitably and necessarily be increased in a strict proportion to the increase in distance. On the other hand, it would not be wise to rely on any definite reduction or discount from the full 100% of work required, since to do so implies that, with the lessened distance, there would be some loafing on the part of the track-gang, or that with the added distance the men would be overworked or would be compelled to slight their work. Therefore it is only safe to allow the full 100% addition for Item 1, repairs of roadway.

The items, renewals of rails and renewals of ties, should certainly be considered as changing in direct proportion to the distance. The repairs and renewals of bridges, culverts, fences, road crossings, signs, cattle-guards, buildings and fixtures, and docks and wharves (Items 4 to 7), may perhaps be considered in the same way, although there are some of these items on which the effect is more doubtful. If a proposed change in line does not involve any difference in the number of streams crossed, then the number of the bridges and culverts will not be altered, and although the size *may* be altered, the effect of the change on the cost for repairs will probably be too insignificant for notice. For small changes of distance it may very readily happen that no bridge or culvert is involved. For great changes of distance, especially those which would involve an entire change of route for a distance of many miles, it might be proper to consider Item 4 to be affected fully 100%. Although Item 4 is small, averaging about 2.5%, the error involved in this item by considering that the change amounts to 100% for great distances and zero for small distances will be almost inappreciable. For Item 5 the full 100% will be allowed for all changes of distance, for the same reason as previously given for repairs of roadway. Item 6 will usually be absolutely unaffected by a small change in distance, since it does not usually involve any buildings or fixtures. Larger changes of distance will probably require some change in the number of minor buildings required, but such buildings will be the more insignificant buildings, and we are therefore making ample allowance, if, under ordinary conditions, we estimate that 20% of the average cost of all buildings (which include terminals, etc.) is allowed for this item. Under ordinary conditions Item 7 will be absolutely unaffected by any changes in alinement which the engineer may make. An addition to distance will not usually affect the telegraph system, except as it adds to the number of telegraph-poles and to the amount of wiring and pole fixtures. Therefore any addition to distance will not add more than 50% to the average cost of this item. Items 9 and 10 are insignificant in amount, and can hardly be said to be affected by any small difference in distance which would ordinarily be measured in feet. Larger differences, which are measured in miles and which may involve, for instance, all the blank forms required for the reports of an additional section-gang, additional pay-rolls, etc., will be increased to practically their full proportion. Therefore there is but little error involved in allowing 100% on these items for changes of distance measured in miles.

139. **Effect on maintenance of equipment.**—The relation between an increase in length of line and the expenses of Items 11, 17, 18, and 19 are quite indefinite. In some respects they would be unaffected by slight changes of distance, and yet it is difficult to prove that the expenses should not be considered proportionate for the distance. For example, the added train-mileage will increase repairs of rolling-stock, and will therefore hasten the deterioration and increase the cost of "repairs and renewals of shop machinery and tools" (Item 17). Fortunately, all these items are so small, even in the aggregate, that little error will be involved, whatever decision is made. It will therefore be assumed that these items are affected 100% for

large additions in distance and 50% for small additions. Item 16 is evidently unaffected by any change of distance. Items 12, 13, 14, and 15 are therefore the only items which remain to be discussed, but their determination requires very careful computation.

These four items constitute the repairs of the rolling-stock of the road. The deterioration of rolling-stock, which requires its repair and finally its ultimate abandonment and therefore renewal, is caused by a combination of a large number of causes, of which the mere distance they travel on the road is but one cause. They deteriorate first with age; second, on account of the strains due to stopping and starting; third, on account of the strains and wear of wheels due to curved track; fourth, on account of the additional stresses due to grade and change of grade, and fifth, ona ccount of the work of pulling on a straight level track. In addition to this, locomotives suffer considerable deterioration due to expansion and contraction, especially of the fire-box when the fires are drawn and the fire-box and boiler become cold, and again when the fire is started up. A large part of the expenses of maintaining passenger-cars is the expense of painting, which is a matter of mere time. Considering that the changes of distance, whose economic value the engineer tries to compute, will never make a difference in the number of round trips the engine or car would make in a day or month, the added distance which may be traveled does not add to the exposure of the car to the weather. Therefore, whatever deterioration of the car paint is due to weather, it will be incurred regardless of whether the length of the division of the road is 100 miles or 99 or 101. That element of the cost of car maintenance is absolutely independent of the precise length of that division of the road. On the other hand, the wear of car- and engine-wheels, although largely affected by curvature, is certainly affected to some extent by wear on a straight tangent. To determine the proportion of total wear due to these various causes is a matter of estimation and judgment. An approach to accuracy may be made by a compilation of the shop records of rolling-stock, repairs, showing the amount which is spent in various kinds of repairs, and estimating as closely as possible what is the cause of each form of deterioration. A check on any such estimate is the consideration that the total deterioration is simply the summation of the deterioration due to all causes combined. It is therefore a question of dividing 100% into as many portions as there are contributing causes, and to assign to each cause its relative importance in per cent, so that the sum total shall reach 100. A. M. Wellington, in his "Economic Theory of Railway Location," distributed the cost of engine repairs to its various contributing causes, as shown in the following tabular form. He

TABLE XXIII.—DISTRIBUTION OF THE COST OF ENGINE REPAIRS TO ITS VARIOUS CONTRIBUTING CAUSES. (Copied from Wellington.)

Item.	Total cost of item.	Distribution.				
		Effect of time, age, and exposure, per cent.	Stopping and starting at way stations, per cent.	Terminal: getting up steam, making up trains, per cent.	Curvature and grades, per cent. (Approximate average.)	Distance on tangent between stations, per cent.
Boiler	20.0	......	2.	7.	4.	7.
Running gear	20.0	......	4.	2.	7.	7.
Machinery	30.0	1.	7.	3.	5.	14.
Mountings	......	......	......	......	......	......
Lagging and painting	12.0	4.	......	2.	......	6.
Smoke-box, etc	5.0	1.	......	1.	......	3.
Tender:						
Running gear	10.0	......	2.	1.	3.	4.
Body and tank	3.0	1.	......	1.	......	1.
Total	100.0	7.	15.	17.	19.	42.

did not claim that such an estimate was accurate and applicable to all cases, but he did claim that the error was probably not sufficient to be of importance. A comparison of these percentages, with the data given by shop records on any particular road, would not probably show a very material difference, and the writer will not attempt to claim that any figures he might obtain will be any more accurate in general, although they might be more accurate as applied to some particular conditions.

It may be noted from the above table that 42% of engine repairs has been assigned to distance on a tangent between stations. If the added distance does not imply an extra stoppage of the train, there is but little, if any, reason to differentiate between the effect on repairs of a large or small addition to distance. We will therefore consider Item 12 to be affected in this ratio of 42%.

Wellington similarly distributed the cost of freight-car repairs to its various causes, and by a very similar method estimated that 36% of such repairs were due to distances on a tangent between stations. The considerable transformation in the construction of freight-cars, since the time that Wellington compiled this table, has certainly utterly changed the absolute cost of car repairs, even if it has not changed the relative percentage of the cost of the various items. In the lack of any better figures this same figure will be used for Item 14. Although there are evidently enormous differences between Items 14 and 15, Item 15 is so small that it is hardly worth the calculation of any more precise figures, and therefore the same ratio, 36%, will be used for Item 15. Wellington made no definite calculation for the itemized cost of passenger-car repairs, but contented himself with using the same figure as for freight-cars, 36%. Such a percentage is probably very much too high, since it is estimated that about one-half the cost of passenger-car repairs is due to the work of painting, inside and out, and of maintaining the seats and upholstery in proper condition. Such repairs are chiefly a function of time, and are but little, if any, dependent on mere distance between stations. It is therefore considered that the passenger-car repairs will not be affected more than 20% by any addition of distance.

140. Effect on conducting transportation.—Item 20, superintendence; Items 30 and 31, station expenses; Item 32, switching charges; Item 34, hire of equipment, and Items 38 to 46 will evidently be nearly, if not quite, unaffected. The most of them are absolutely unaffected.

141. Item 21. Wages of engine- and roundhouse-men.—In a previous chapter (§ 62) the wages of enginemen and roundhouse-men have been discussed. It is evident that the wages of roundhouse-men will be totally unaffected by a change of distance. The proportion which the wages of roundhouse-men bears to the total item has fluctuated between large limits during the past ten years. It has averaged 9%. The discussion of wages showed that even the enginemen are rarely, although sometimes, paid on a strict mileage basis. They are usually paid on a trip basis, in accordance with which a slight change in the distance will not affect the classification of the trip, and therefore would make no difference in the wages. We will therefore say that for small changes of distance, especially such as would be measured in feet, this item will be unaffected; but that for larger changes, such as would be measured in miles, this item will be affected by the full amount of the enginemen's wages, which we will put down at the average value of 91% of the total item.

142. Item 22. Fuel.—A surprisingly large percentage of the fuel consumed is not utilized in drawing a train along the road. A portion of this percentage is used in firing-up. A portion is wasted when the engine is standing still, which is a considerable proportion of the whole time.

The policy of banking fires instead of drawing them reduces the injury resulting from great fluctuations in temperature, but in a general way we may say that there is but little, if any, saving in fuel by banking the fires, and therefore we may consider that almost a fire-box full of coal is wasted whether the fires are banked or drawn. Some tests were made on the Santa Fé, in which some large locomotives consumed from 1200 to 1660 pounds of coal merely in firing-up. But even the amount of coal required to produce the required steam-pressure in the boiler from cold water does not represent the total loss. The train-dispatcher, in his anxiety that engines shall be ready when needed, will sometimes order out the locomotives which remain somewhere in the yard, perhaps exposed to cold weather, and blow off steam for several hours before they make an actual start. Of course the amount thus attributable to firing-up is a very variable one, depending on the management, and therefore no precise figures are obtainable. But it has been estimated that it amounts to from 5 to 10% of the total consumption. A freight-train, especially on a single-track road, will usually spend several hours during the day on sidings, and when a single-track road is being run to the limit of its capacity, or when the management is not good, the time will be still greater. It has been found that the amount of coal required by an engine merely to keep up steam will amount to from 25 to 50 pounds per hour. If, in addition to this, steam escapes through the safety-valve, the loss is much larger. It is estimated that the amount lost through a 2½-inch safety-valve in one minute would represent the consumption of 15 pounds of coal, which would be sufficient to haul 100 tons on a mile of track with easy grades. Again we see that the amount thus lost is exceedingly variable and almost non-computable, although as a rough estimate the amount has been placed at from 3 to 6% of the total. Another very large subitem of loss of useful energy is that occasioned by stopping and starting. A train running 30 miles per hour has enough kinetic energy to move it on a straight level track for more than two miles. Therefore, every time a train running at 30 miles per hour is stopped, enough energy is consumed by the brakes to run it about two miles. There is a double loss, not only due to the fact of the loss of energy, but also because the power of the locomotive has been consumed in operating the brakes. When the train is again started, this kinetic energy must be restored to the train in addition to the ordinary resistances which are even greater, on account of the greater resistance at very low velocities. Of course, the proportion of fuel thus consumed depends on the frequency of the stops. It was demonstrated by some tests on the Manhattan Elevated Road in New York City, where the stops average one in every three-eighths of a mile, that this cause alone would account for the consumption of nearly three-fourths of the fuel. On ordinary railroads the proportion, of course, will not be nearly so great, but there is reason to believe that 10 to 20% is not excessive as an average figure. The amount of fuel which is consumed on account of curvature is, of course, a function of the curvature and will vary with each case. The only possible basis for a calculation of this amount must be somewhat as follows: Since all of the above calculations consider the average cost of a train-mile throughout the country, we must consider what is the average amount of curvature per mile of track throughout the country. By estimating, as will be developed in the next chapter, the proportion of the fuel expenditure which is due to this average amount of curvature and subtracting this, as well as the other subitems enumerated above, from the total average cost of a train-mile, we would then have the desired quantity, the cost of fuel per mile of straight level track. Although it is not easy to obtain reliable statistics showing the average curvature per mile of road throughout the United States, there is reason to believe that it is not far from 35° per mile. According to the method of calculations given in the next chapter, to determine the additional fuel consumed by the added resistance due to 35° of curvature per mile, we obtain the approximate value that about 4% of the fuel consumption will be due to this cause. To obtain an average figure for the resistance due to grade is perhaps even harder, but on the approximate basis that the average amount of rise and fall per mile of track is about 11 feet per mile, it would seem as if 25% of the consumption of fuel were due to grades. Summarizing the above items we would have

Firing.	5 to	10%	
Loss by radiation, etc. . .	3 to	6%	
Stopping and starting ...	10 to	20%	
Average curvature.	4 to	4%	
Average grade.	25 to	25%	
	47 to	65%	
Direct hauling.	53 to	35%	Average 44%
	100	100	

This gives, as an average figure for the increased consumption of fuel due to one additional mile of straight level track, 44% of the average consumption per mile.

143. Items 23, 24, and 25. Minor engine-supplies.—If water is obtained from municipal supplies and paid for at meter rates, then the cost will be strictly according to the consumption which will be nearly according to the number of engine-miles. Almost the only waste would be that occasioned by blowing off steam. Under such circumstances the increase in this item would be very nearly 100%, but, on the other hand, where the supply is obtained from the company's own plant, there is hardly any appreciable increase in expense due to the extra draft on the tanks. Of course the cost of pumping would be somewhat affected. Considering that the sum of Items 23, 24, and 25 are only 1.26%, very little error would be involved if we consider as an average figure that this item will be increased 50% by any addition to distance.

144. Item 26 includes the wages of trainmen other than enginemen. Their wages are paid on very much the same basis as the enginemen, which means usually that small additions of distance will not affect their wages. Large additions will affect them 100%.

145. Item 27. Train-supplies and expenses include a very large matter of small subitems, the consumption of which is partly a matter of mere time and partly a matter of mileage. It is sufficiently precise in this case to say that 50% of these subitems will be affected directly as the mileage.

146. Item 28. Switchmen, flagmen, and watchmen.—The necessity for flagmen and switchmen may be said in general to increase with the mileage, although it might readily happen that a given change in distance which is under consideration might not effect the slightest change in this item. It is quite unlikely that the number of switchmen would be affected. It is probable that 25% of this item is sufficient as an average figure.

147. Item 29. Telegraph expenses include the wages of operators at stations (which are unaffected) and the special expenses due to offices and telegraph stations and to operating the line, the maintenance of the line being charged to Item 8. Although it will theoretically require more battery material to transmit telegrams over a longer line, the added expense is so very slight that it may be utterly ignored.

148. Item 33. Car-mileage.—As before stated, car-mileage is now largely paid for on the per-diem basis,

TABLE XXIV.—EFFECT ON OPERATING EXPENSES OF GREAT AND SMALL CHANGES IN DISTANCE.

No. of item.	Normal average.	Per cent affected.		Cost per mile.		No. of item.	Normal average.	Per cent affected.		Cost per mile.	
		Great.	Small.	Great.	Small.			Great.	Small.	Great.	Small.
							22.906	....	....	13.89	5.15
*1	10.767	100	100	10.77	10.77	26	7.288	100	0	7.29	0
2	1.422	100	100	1.42	1.42	27	1.519	50	50	.76	.76
3	2.948	100	100	2.95	2.95	28	4.110	25	25	1.03	1.03
4	2.461	100	0	2.46	0	29	1.875	0	0	0	0
5	.542	100	100	.54	.54	30	7.310	0	0	0	0
6	2.151	20	0	.43	0	31	.728	0	0	0	0
7	.249	0	0	0	0	32	.319	0	0	0	0
8	.150	50	50	.07	.07	33	1.829	0	0	0	0
9	.029	100	0	.03	0	34	.287	0	0	0	0
10	.315	100	0	.31	0	35	.863	100	100	.86	.86
						36	.959	100	100	.96	.96
	21.034	....	....	18.98	15.75	37	.179	100	100	.18	.18
						38	.846	0	0	0	0
11	.617	100	50	.62	.31	39	.429				
12	6.538	42	42	2.75	2.75	40	1.609				
13	2.174	20	20	.43	.43	41	.128				
14	7.160	36	36	2.58	2.58	42	.112				
15	.198	36	36	.07	.07	43	1.723				
16	.207	0	0	0	0	44	.460				
17	.570	100	50	.57	.28	45	.624				
18	.042	100	50	.04	.02	46	.533				
19	.518	100	50	.52	.26						
							56.636	....	....	24.97	8.94
	18.024	....	....	7.58	6.70						
						47	4.306	0	0	0	0
20	1.757	0	0	0	0	48					
21	9.607	91	0	8.74	0	49					
22	10.316	44	44	4.54	4.54	50					
23	.647	50	50	.32	.32	51					
24	.377	50	50	.19	.19	52					
25	.202	50	50	.10	.10	53					
	22.906	....	....	13.89	5.15		100.000	....	....	51.53	31.39

* For the significance of the items, see Table IX.

although it is sometimes paid for on a combined mileage and per-diem basis. On the strict per-diem basis an addition of a few hundred feet or even several miles would have no effect. On a strict mileage basis the item would be affected in proportion to the distance. Considering the very extensive adoption of the per-diem system, it is probably nearer to the truth to consider that the item is practically independent of distance, and therefore it will be here ignored, although there are cases where it should be included to its full value.

149. Items 35, 36, and 37. **Expenses and damage,** although fortuitous and not items that can be definitely calculated or predicted, should nevertheless be allowed for their full value for any added distance.

The general expenses, Items 47 to 53, will be unaffected.

150. Estimate of total effect on expenses of small changes in distance (measured in feet); also estimate for distances measured in miles.—Collecting the above percentages for the various items we have Table XXIV, which shows that the average cost of operating a small additional distance will be about 31.39% of the average cost per unit distance. If the additional distance amounts to several miles, the added cost will amount to about 51.53% of the unit cost. These figures may also be considered as the saving in operating expenses resulting from a shortening of the line, and thus gives a measure of the operating value of reducing the length of the line. The average cost of a train-mile from 1890 to 1904 varied between 91.829 c. in 1895 to 131.375 c. in 1904. The cost has been rising steadily since 1897. Whether the cost will continue to rise or whether it will recede during the next few years is of course a matter of pure conjecture. There are many reasons to believe that the cost will recede somewhat from the high value of recent years, although it may never again sink to the low value of 1895. If we adopt the round number of \$1.30 as the probable cost of a train-mile during the next few years, we can reduce the above percentages to cents per train-mile, which will come to 41 and 67 c. per train-mile respectively. Some trains run 365 days per year; others run but 313 days. The tendency, however, is toward the larger figure, especially in the case of freight service, which comprises about 55% of the number of train-miles. The added cost per daily train per year for *each foot* of distance would therefore be

$$\frac{41 \times 365 \times 2}{5280} = 5.67 \text{ c.}$$

When the distance is measured in miles the added cost per daily train per year for *each mile* of distance would be

$$67 \times 365 \times 2 = \$489.$$

Of course, if such calculations are made for a light traffic road which only runs trains on week-days, we should use 313 in the above equations instead of 365. It should be noted that the subitems in the above table which are the most uncertain are those whose absolute value is the smallest, and that even if we make very large variations in the most uncertain items, the final result will not be very materially altered. On the other hand, the very largest items are those which are capable of fairly precise calculations. The numerical illustration of the capitalized value of saving distance will be given later, see § 177.

Effect of Distance on Receipts.

151. **Classification of traffic.**—Although there are numerous methods of classifying traffic, the best classification for the purpose of this discussion is to divide all traffic into

two general divisions, through traffic and local traffic, the through traffic being here considered to mean traffic which passes over two or more roads, even though the total haul may be less than 100 miles. On the other hand, local traffic is here considered to mean traffic that is entirely confined to one road, even though it travels from one end of the system to the other. The following discussion will require a subdivision of this classification into five classes:

(*a*) Non-competitive local—on one road with no choice of routes.

(*b*) Non-competitive through—on two or more roads, but with no choice.

(*c*) Competitive local—a choice of two or more routes, but the entire haul may be on the home road.

(*d*) Competitive through—direct competition between two or more routes, each passing over two or more lines.

(*e*) Semi-competitive through—a non-competitive haul on the home road and a competitive haul on foreign roads.

It will be found that any other possible combination of conditions may be placed under one of the above five classes, so far as its essential effect on receipts is concerned. In this discussion the term "home road" applies to the road with whose finances we are directly concerned. The term "foreign road" applies to any other road with which traffic is exchanged, and which may or may not suffer loss through any change of policy on the home road.

152. Method of division of through rates between the roads on which through traffic is carried.—In theory through rates are divided between the roads run over in proportion to the mileage. Frequently there is an arbitrary deduction made from the gross amount received to pay for "terminal charges" before the division is made. It sometimes happens that a road has sufficient financial strength in its dealings with other roads to demand and obtain the concession of a "constructive mileage," which is in excess of the actual mileage. For instance, the railroad may have been running for many years with a certain mileage between termini. Then a cut-off is made by means of a tunnel or some other very expensive construction, and there may be an actual saving of several miles in the length of the road. If the road is financially strong, it may succeed in obtaining the concession of dividing the freight receipts according to the old system rather than to submit to the reduction on account of the improvement. Nevertheless the fact remains that receipts are supposed to be divided according to the relative mileage. The words "through rate" in the following discussion refer to the amount actually divided after preliminary deductions have been made. Our discussion must therefore be based on that method, and any variations from it must be considered as exceptions. On account of this method of division and on account of the fact that non-competitive rates are almost invariably fixed according to the mileage, there results the unusual feature that, unlike curvature and grade, there is a compensating advantage in increased distance, which applies to all of the above classes of traffic except one (*c*—competitive local), and that the compensation is sometimes sufficient to make the added distance an actual source of profit. It has just been proved that the cost of hauling a train an additional mile is only from 31 to 51% of the average cost. Therefore in all non-competitive business (local and through) where the rate is according to the distance, there is an actual profit in all such added distance. In competitive local business, in which the rate is fixed by competition and has practically no relation to distance, any additional distance is but dead loss without any compensation. In competitive through business the condition of profit or loss will depend on the ratio of the length of the home haul to that of the foreign haul. The effect of this ratio and the law under which it works may best be illustrated by numerical examples.

153. Effect of a change in the length of the home road on its receipts from through-competitive traffic.—Suppose that the home road is 100 miles long and the foreign road is 150 miles long. Then the home road will receive $\frac{100}{100+150}=40\%$ of the through rate. Suppose that the home road is lengthened five miles. Under this condition it will receive $\frac{105}{105+150}=41.176\%$ of the through rate. The traffic being competitive, the rate will be a fixed quantity regardless of this change of distance. To simplify the numerical work we will consider how much the home road will receive on a total freight charge, which, on account of the competition, is fixed at $1. By the first plan the home road will receive 40 c. and therefore handles that consignment of freight at the rate of .4 c. per mile. When the distance is increased to 105 miles it receives for the handling of that consignment of freight 41.176 c. Instead of computing the average rate per mile, we will consider it as though it received the same rate for the original hundred miles, and that it received 1.176 c. for the additional five miles, or at the rate of .235 c. per mile; but this is at the rate of 59% of the original rate per mile. We have determined above that the cost per train for an additional mile averages about 51.5% of the average cost of a mile, and therefore it may be seen that the net effect of adding that five miles is to leave to the original 100 miles the full rate of profit, and also that the amount received for the additional five miles will more than pay the cost of it, even though the additional profit is small. On the other hand, if the line is shortened five miles it may be similarly shown that not only are the receipts lessened in gross amount, but that the saving in operating expenses by the shorter distance is less than the reduction in receipts.

This line of argument was used by the manager of a railroad in opposing the plan of the directors to shorten a road by means of an expensive tunnel. He argued that under their traffic agreements the receipts of the road would not only be less, but also that the resultant saving in operating expenses would not equal the reduction in receipts.

154. A second example will be considered to illustrate another phase. Suppose that the haul on the home road is 200 miles and that on the foreign road is 50 miles. In this case the home road will receive $\frac{200}{200+50}=80\%$ of the through rate. Suppose that the home road is lengthened five miles, then it will receive $\frac{205}{205+50}=80.392\%$ of the through rate. Assuming as before that the total payment on a given shipment of freight is $1, the home road will receive by the first plan 80 c., or at the rate of .4 c. per mile. Adding five miles, the home road will receive only .392 c. in addition, which will be at the rate of .0784 c. per mile for the additional five miles. This is only 19.6% of the original rate, and is but little over one-third of what the additional distance will actually cost. In such a case, although there is some compensation for the additional distance, it is not sufficient to pay for the added cost. A study of the two numerical problems given above will show that there is some proportion of home haul to foreign haul at which the added receipts will just equal the added cost. When the home haul is a very large proportion of the total haul there is a loss, although not a total loss. When the haul is entirely on the home road, which is the case of competitive local traffic, the added distance is a complete loss without any compensation.

When the added distance is a large part of the home haul and the foreign haul is very large, then the profit of the home road is considerable and the total transaction is distinctly profitable. A further development of this course of reasoning might be an interesting mathematical study, but its precise application is useless for the reason given below.

155. Application of the above principle.—Every station on the home road has at least potential traffic relations with every other station on every other road in the country. The traffic between each station and every other station presents a new combination. The effect of an increase of distance on one branch of the traffic will be more or less compensated by an opposite effect on the traffic between two other stations. The net effect on the total receipts of the road could only be obtained by the solution of a problem with a very large number of elements which are not even constant, but which are subject to unforeseen changes. Therefore the only practical use that we can make of a demonstration like the above is to derive from them certain general conclusions as follows.

156. General conclusions regarding a change in distance.—(*a*) In all non-competitive business (local and through) the added distance is actually profitable. On some small roads practically all of the business is non-competitive. A considerable proportion of it is always non-competitive.

(*b*) When the competitive local business is very large and the competitive through business has a large average home haul compared with the foreign haul, the added distance is a source of loss. Such conditions apply almost exclusively to trunk lines and to competitive lines between large cities.

(*c*) The above conclusions may be still further condensed to the general conclusion that there is always *some compensation* for the added cost of operating an added length of line, and that it may sometimes be a source of profit.

(*d*) There is a danger in the application of the above argument which should not be forgotten. The argument might be carried to the logical conclusion that if added distance is profitable the engineer would be justified in purposely lengthening the line. But added distance means adding operating expenses. The increased tariff to meet these is a tax on the community, a tax which more or less discourages traffic. It is not only contrary to public policy but contrary to the ultimate best interests of the road to burden an enterprise with avoidable expenses. The locating engineer frequently has to choose between two locations, one of which saves distance by very expensive construction, such as deep cutting, high embankments, a tunnel or a bridge, while a longer line may be constructed at considerably less total expense, because it is almost a surface line. In such a situation the engineer should consider that if the bulk of the business of his road will be "non-competitive local," he would hardly be justified in increasing the cost and thereby actually reducing the mileage and the gross receipts of his road. On the other hand, if the road is a very important line, on which the bulk of the business is apt to be "competitive through" business, the added distance would probably be operated at a considerable loss, and therefore should be avoided even at a considerable added expenditure.

(*e*) Finally, although there is a considerable and uncompensated loss resulting from curvature and grade which will justify a considerable expenditure to avoid them, there is by no means as much justification to incur additional expenditure to avoid distance. Of course, needless lengthening should be avoided as a matter of broad policy. A moderate expenditure to shorten the line may be justifiable, and its justification will increase with the increase in probabilities of a heavy through competitive traffic. A short branch line, whose business will consist chiefly of non-competitive local business or of through business, in which the proportion of foreign haul to home haul will be large, will receive a very considerable compensation if not actual profit on added haul, and therefore will not be justified in paying any great amount of money to reduce distance.

157. Justification of decreasing distance to save time.—A little study of this question will show that the cases are rare where a minor change in distance will accomplish any material saving in the time required to make a trip. It will also be clear that such a saving of time will have no effect on freight business which is worth considering. The competition for passenger business between two cities like New York and Philadelphia, or even New York and Chicago, render the time element of considerable financial importance, but it may readily be demonstrated that the saving of even ten minutes on such a trip by means of a change of alinement, the average speed of the trains remaining the same, could only be accomplished by enormous expenditure. The cases are very rare where the element of time as affected by reduction of distance can be given financial weight.

158. Effect of change of distance on the business done.—All of the above calculations have assumed for simplicity that the business done by the road is a definite quantity which is unaffected by any proposed changes. A common defect in the location of a cross-country line, whose business will virtually be that of a branch to some great trunk line with which it may connect, even though the small road is an independent road, is that too much importance will be given to the effort to obtain "a short, straight line" rather than a line which will reach sources of traffic. Of course there is a danger in either extreme. A line which zigzags across country in an effort to reach every possible source of traffic may be so long that the whole traffic is burdened with an excess haul which will literally discourage traffic. The number of elements entering into the problem is so large that it is difficult to state a general rule, but the following will usually be safe. Adopt a route of such a length that the annual traffic per mile of line is a maximum. We may make the rule somewhat more complicated and allow for the element of cost of construction by saying—Adopt a route of such length that the annual traffic per mile of line divided by the average cost per mile is a maximum. Even the above rules take no account of the effect of curvature and grade, which will, of course, have a considerable effect on the operating expenses; but a road whose receipts per mile of line is maximum is evidently obtaining the maximum profit from the community, especially if the cost of construction has been kept so low that the profits per mile of line divided by the average cost is also a maximum.

No attempt has been made to estimate the effect of a saving of time on the passenger business of the very few trunk lines on which the competition in the matter of speed is so great that millions are freely spent in the attempt to reduce it, not only by a reduction of distance but by the elimination of curvature and steep grades. A gain in traffic which is secured wholly by competition only holds good as long as the advantage can be maintained and until a competitor will offer still greater advantages. Under these conditions any exact analysis of the question is practically impossible, and considering the fact that such a question does not apply to any appreciable extent to nine-tenths of the mileage of the country, it will not be here further considered.

CHAPTER XIII.

CURVATURE.

159. General objections to curvature.—In the popular mind curvature is perhaps the most objectionable feature of railroad alinement. The popular mind readily perceives the curvature as a fact, when a grade which is more costly from an operating standpoint is not perceived at all. The objections to curvature may be analyzed and classified as follows:

(1) *Danger.*—The added danger of collision, derailment, or other form of accident which is due to curvature, are fully realized and even exaggerated by non-technica people.

(2) *Effect on traffic.*—A road sometimes loses passenger traffic on account of the apprehension of danger, or because the curvature produces rough and unpleasant riding, or because it reduces somewhat the speed of trains and therefore the total time between termini.

(3) *Effect on operating trains.*—Curvature has some limiting effect on the length of trains, and it is claimed that it limits the use of heavy engines.

(4) *Effect on operating expenses.*—Curvature increases these expenses by increasing (*a*) the required tractive force; (*b*) the wear and tear of road-bed and track; (*c*) the wear and tear of equipment; and (*d*) the required number of track-walkers and watchmen. The above objections will be considered in order.

160. Financial value of the danger of accident due to curvature.—This subject has already been considered in Chapter I, under the general subject of accidents. Special objection is urged against curvature, on the ground that it increases the danger of accidents, that accidents are more liable to occur on a curve than on a straight track, and that when they do occur the results are apt to be far worse than when on a tangent. The subject is sometimes considered from the standpoint of eliminating curvature altogether, but this is usually financially if not physically impossible. We are chiefly concerned from a practical standpoint with an effort to obtain easy curvature rather than sharp curvature, or to reduce the number of degrees of central angle. If we study the statistics published each year regarding the total number of railroad accidents in the country and attempt to estimate the number which happened on curves, and then attempt to estimate the number of those accidents which would have been avoided if the track had not been curved, or if the track had had easy curvature rather than sharp curvature, it will be found that the estimated number for which curvature, and especially sharp curvature, was directly responsible is very small. If we can estimate the number of railroad curves in the United States, the immense train mileage on them, and then compute the probabilities that an accident will happen on any one particular curve during any year or during a term of say 100 years, we will find that the probabilities are exceedingly small. If we then attempt to compute, on the basis of these probabilities, how much money should be annually expended in order to avoid an accident which might probably happen in the course of the computed term of years, we would find that this annual sum would be absolutely insignificant. In fact we are forced to the conclusion that we are not justified in spending money to reduce curvature on account of the danger of accident. Of course this does not mean that there are not special cases in which accident is especially liable to happen and which thoroughly justifies a demand of expenditure to avoid it. For example, a very sharp curve in a mountainous region may circle around the end of a steep ridge, so that the view of the track is obstructed and prevent the engineer from discovering a landslide which might fall down from the steep side slopes. Such a case is an example of many cases of special danger which justify and demand the employment of special watchmen and flagmen to watch the condition of such dangerous places in the road. But these are simply exceptions which have no application to the general rule. We may therefore dismiss this phase of the question.

161. Effect of curvature on traffic.—It is well known that the sharp curvature found on some of our east and west lines passing over the Allegheny Mountains has some effect in deterring travel from those lines. Women and children will grow "car-sick" while passing around some of these sharp curves at a comparatively high speed. But, on the other hand, a road which is so located usually has the compensation of attractive mountain scenery which may attract additional travel to an extent as great, if not greater, than the loss due to the crooked line. Again it must be considered that such an objection will only apply to a very small proportion of the competitive passenger traffic. The great bulk of the passenger traffic is unaffected while the freight traffic is absolutely unaffected. We are therefore justified in throwing this consideration out of account. Analogous to the above is the objection that a crooked line reduces the ability to make fast time and may deter travel on account of the apprehension of danger, but we may again consider, as above stated, that its effect is exceedingly small, and that whether small or large the general character of the country will absolutely prevent any change of plan which will materially affect the road in that respect. We are therefore justified in eliminating this phase of objections from our financial calculations.

In the chapter on Distance (§ 157) we have already considered the justification of a reduction of distance in order to save time on roads having a very large amount of competitive passenger traffic. On just such roads the reduction of even the rate of curvature assumes financial value. When express-trains are required to make an average speed, for considerable distances of more than 60 miles per hour, the reduction of the rate of curvature becomes an important matter, since at such a speed the superelevation of the outer rail on curves of even moderate curvature becomes so high that it is objectionable, and the operation of such curves at high speed becomes dangerous. Even the nervous strain on the engineman, due to watching for danger when rounding a sharp curve at very high speed, cannot be ignored, and on this account many railroads will spend considerable money to increase the radius of curvature, even though they are unable to reduce the number of degrees of central angle; but all these considerations apply only to that very limited portion of the traffic on a very small percentage of the total railroad mileage. Very few engineers ever have occasion to consider such cases.

162. Effect of curvature on the operation of trains.—It is true that curvature does increase the resistance to traction and that uncompensated curvature, when located on a ruling grade, virtually adds to the rate of that grade, and therefore might have a limiting effect on the length of trains which would prove very serious. This, however, can almost always be avoided by compensation for curvature. There are a few very rare cases, of which the

Hudson River Railroad is the most conspicuous example, in which the general grade of the road for many miles is almost level, and yet where, on account of the rocky bluffs on the river-bank, sharp curvature is unavoidable, except by enormous expenditure. In such a case curvature may actually have a limiting effect on the length of trains, but such an exception is so very rare that it need not in general be considered.

Limiting the use of heavy engines.—It has been asserted that very sharp curvature will prevent the use of the heaviest types of engines. While such an objection will probably have some force, if applied to abnormally sharp curvature, such as 18° or 20° curves, it hardly has any force for curves which are even as sharp as 10° curves. The "consolidation" engine was originally designed for use on the sharp curves and steep grades of the mountain division of the Lehigh Valley Railroad. It has even been claimed as the result of tests that the consolidation engine has less resistance per ton on sharp curves than an engine of the "American" type. Although these tests have been subject to question regarding their accuracy, it is quite evident that they were sufficiently accurate to prove that sharp curvature does not prevent the use of heavy engines or even make an abnormal reduction in their efficiency on sharp curves.

We therefore reach the only rational objection to curvature which may be directly computed in dollars and cents, and that is the increase in operating expenses.

Effect of Curvature on Operating Expenses.

163. Relation of radius of curvature and of degrees of central angle to operating expenses.—It does not need proof that the sharper the curvature the greater will be the tractive force required. The rail wear and also the general wear and tear on road-bed and track per foot of length will also be increased. If we attempted to establish a relation between operating expenses and the radius of curvature, we would also have to consider the total length of the curve before we could determine the true effect on the operating expenses of any particular curve. A method of calculation, which is much more simple and which is sufficiently accurate for the purpose, may be made by establishing a relation between operating expenses and the number of degrees of central angle in a curve. The outline of the method is as follows:

(1) It has been found that if two tangents, which make an angle Δ, are connected by a curve of large radius, such as the curve *AB*, the total cost in operating expenses

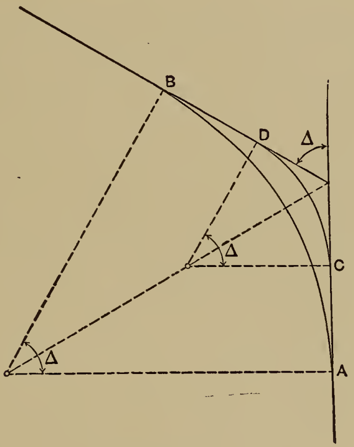


Fig. 30.

for the curve *AB* will not be materially different from that of the track *ACDB*, which has the sharp curve *CD*. Of course the wear on the sharp curve *CD per foot of length* will be much greater than the wear per foot of length on the track *AB*, but, on the other hand, the reduction of average track expenses per foot on the straight track *AC* and DB will cause the general average for track expenses to remain substantially the same. Therefore we may say that when we are compelled to change the course of a line by so many degrees of central angle, it makes no material difference, so far as track expenses are concerned, whether we employ a sharp curve or an easy curve. The sharp curve will concentrate the *increase* of expenses to within a few feet. The easy curve will merely spread it over a greater distance, but the total *extra* cost of the curve will be substantially the same in either case.

The distinction between the desirability of reducing the rate of curvature in order to attain high speed and the extra cost of operating freight-trains, and the comparatively low-speed passenger-trains which comprise the business of perhaps 90% of our railroad mileage, must be here clearly appreciated. Although no accuracy is claimed for such a broad statement, it is much more nearly true than any other statement regarding curvature which has equal simplicity.

(2) At what degree of curvature is the total train resistance double its value on a tangent? No one figure will be exact for all conditions. Train resistance varies with the velocity and with the various conditions of train loading even on a tangent, and the ratio of train resistance on a curve and on a tangent varies according to the conditions. As an approximate statement, we may say that a train running at average velocity on a 10° curve will encounter an extra resistance due to curvature which is about equal to the average resistance on a level tangent. We can therefore make a second general statement that on a 10° curve the resistance will be double the resistance on a level tangent.

(3) The cost of operating a train one mile is approximately so much, say $1. If we double the tractive resistance, we will increase certain items of expenditure,

although many other items are unaffected. The combined value of the affected items will aggregate a certain proportion of the cost of a train-mile. A mile of continuous 10° curve contains 528° of central angle, and on the basis of assumption (2) a mile of such track will double the tractive resistance. Therefore, each degree of central angle is responsible for $\frac{1}{528}$ of the extra cost of the double tractive resistance. Since the increase as computed is irrespective of the radius and depends only on the number of degrees of central angle, we may therefore say that each degree of central angle of a curve will add that computed percentage to the average operating expense of a train-mile.

This percentage however is based on the extra cost of a curved track over a straight level track. The average figures which we have for the cost of a train-mile are based on the cost of an average mile as it actually exists, including all grades and curves. This cost will evidently be somewhat greater than the cost of operating one mile of straight tangent; but when we consider that the *average* amount of curvature per mile of track and the *average* amount of grade per mile of track is quite small, and that its influence in many items in the cost of operating a train-mile is very small, if not zero, we can appreciate the fact that, while the cost of operating a mile of plain level track is far less than that of operating a mile of track with heavy grades and sharp curves, it will not be very much less than the cost of operating a mile of *average* track. Therefore, although we might make some allowance for this item, we could not allow very much.

164. Effect of curvature on maintenance of way.—A very large proportion of the items of expense in a train-mile are absolutely unaffected by curvature. It will therefore simplify matters somewhat if we at once throw out all the unaffected items. Of the items of maintenance of way and structures, all but the first three may be thrown out. Item 4 would be affected in case a bridge or a trestle occurred on the curve considered, but since the very large majority of bridges and trestles are purposely made straight, and that only a very minute proportion of the total length of the curves of a road will be found on its bridges and trestles, the effect of this exceedingly small percentage on the cost of this small item would be so very minute that it may be utterly neglected.

165. Item 1. Repairs of roadway.—A very large proportion of the subitems are absolutely unaffected. The care of embankments and slopes, the ditching, weeding, etc., are evidently unaffected. The track-labor on rails and ties and the work of surfacing will evidently be somewhat increased, and yet it is very seldom that the length of a track section would be decreased simply on account of excessive curvature throughout that section. We are here trying to estimate how much this item, which consists largely of track-labor, will be affected by 528° of central angle per mile. In the previous chapter an approximate estimate was made that the average curvature per mile of road for the whole United States is about 35°. 528° of curvature in a mile probably does not frequently occur. It would mean the equivalent of nearly $1\frac{1}{2}$ complete circles, and yet it is probably a generous estimate to say that the track-labor and other expenses belonging to this item would not be increased more than 25% for such an amount of curvature.

166. Item 2. Renewals of rails.—It has already been demonstrated in Chapter IX, §§ 102 and 103, that the rate of rail wear on curves seems to bear some relation to the stage of that wear in the life-history of the rail, and also that the rail wear is nearly, if not quite, proportional to the degree of the curve. Since the fundamental feature of the method of obtaining the effect of curvature on the operating expenses is to assume that the extra expense varies as the number of degrees of central angle, we may here assume that the law is also applicable to the wear of rails. In § 103 it was computed that the *excess* rail wear on a 10° curve would be 326% of the rail wear on a tangent. Wellington assumed that the extra rail wear on a continuous 11° 20′ curve would be 300%, which would be the equivalent of 268% extra rail wear on a 10° curve. Although the value determined above is considerably more than Wellington's value, it is based on what are perhaps the most complete and reliable series of tests ever made on such a subject, and we will therefore assume the value 326%.

167. Item 3. Renewals of ties.—Curvature affects ties by increasing the rail-cutting and by requiring more frequent respiking, which spike-kills the ties even before they have decayed. Wellington estimates that a tie which will last nine years on a tangent will last but six years on a 10° curve. He adds 50% for tie renewals. He considers the decrease in tie life to be proportional to the degree of curve. This statement is again a verification of the general statement in § 163, that the extra cost per foot of the sharper curvature just balances the extra length of the easier curvature.

168. Effect of curvature on maintenance of equipment.—Items 11, 16, 18, and 19 will be considered as unaffected. There is little if any rational cause for assigning any definite increase in any of these items, owing to curvature of the track.

169. Item 12. Repairs and renewals of locomotives.—Curvature affects locomotive repairs by increasing very largely the wear on tires and wheels, and also the wear and strain due to the additional power required. Since the resistance due to curvature is very small compared to that due to even a moderate grade, this last cause may be neglected altogether. Referring to Table XXIII (§ 139), we find an estimate that 19% of the cost of engine repairs is assigned to curvature and grades combined. Of this amount two-thirds, or, say, 13%, should be assigned to curvature alone. On the basis that the average curvature of the roads of the country is about 35° per mile, which is about one-fifteenth of the 528° of curvature per mile which we are considering, then, if 35° is responsible for 13% increase in engine repairs, 528° would be responsible for 196%. It must be admitted that the above computation is grossly approximate, and that it contains the unwarrantable assumption that the extra cost of engine repairs which is due to curvature will be strictly in proportion to the degrees of curve. Although it is probably not true that 528° of curvature would increase the cost of engine repairs by 15 times the extra cost of 35° of curvature, yet it is probably true that for ordinary variations from that average of 35° per mile the increased cost of engine repairs will be approximately as the number of degrees of curve, and therefore our final value is not necessarily far out of the way. If 35° is responsible for an increase of 13%, 1° would be responsible for about .37 of 1%. In allowing an increase of 196% for 528° we are also allowing .37 of 1% per degree of central angle.

170. Items 13, 14, and 15.—By a similar course of reasoning to that above given, the estimates for Items 14 and 15 will be made 100%, while that for Item 13 will be made only 50%, because such a large proportion of the expenses of Item 13 are due to painting and maintaining upholstery, which have no relation to variations in alinement.

171. Item 17. The repairs and renewals of shop machinery and tools will not be increased more than 50% per mile for the additional repairs required on the above equipment.

172. Effect of curvature on conducting transportation.—An inspection of the items under this general heading will show us that we may at once throw out as unaffected all the items except those which concern engine-supplies, flagmen, and watchmen, and the group which refers to accidents.

173. Items 22, 23, 24, and 25.—The required quantities in this calculation are the additions to cost resulting from the introduction of 528° of central angle into a mile of track. We have assumed that this amount of curvature will exactly double the resistance. We found in Chapter XII (§ 142) that the average increase in fuel consumption due to direct hauling amounts to about 44%. We have here assumed that the added curvature exactly doubles the work. We will therefore charge 44% of the average cost of a train-mile for this extra curvature. Since the consumption of water and other engine-supplies is roughly proportional to the consumption of coal, there will evidently be no error worth considering in assigning this same percentage to Items 23, 24, and 25.

174. Item 28.—There are many cases where a dangerous curve justifies and requires the employment of a special watchman to give timely notice of any dangerous condition of the track. Such special cases would, of course, justify a considerable expenditure to eliminate the dangerous features of that particular location, but such a charge should not be made against curvature in general. Ordinarily the elimination or retention of a curve will not involve the question of watchmen and flagmen in any way. We are therefore justified in disregarding this item altogether as a general proposition, if we keep in mind that the item should be included when we are considering the elimination of some particularly dangerous curve.

175. Items 35, 36, and 37.—This group of items, which refer to accidents and the increased danger of accident due to curvature, and therefore the amount of money which might be justifiably spent to avoid this danger, has already been referred to in § 160. It was there shown that, although there might be special cases which would justify considerable expenditure on account of specific dangers in the situation, we cannot ordinarily give any definite financial value to this item as applied to curvature in general. We therefore must eliminate these items as affecting the cost of curvature in general.

General expenses.—Items 47 to 53 will also be unaffected.

176. Estimate of total effect per degree of central angle.—Compiling the above estimates we have Table XXV. According to the table 528° of curvature in one mile will increase the expenses of each train passing over it by 35.425% of the average cost of a train-mile, and, according to the general principles laid down in § 163, one degree of central angle of any curve, no matter what the radius, will increase the expenses by $\frac{1}{528}$ of 35.425%, or .0671% per degree. Therefore, the cost per year per daily train each way, at the average rate of $1.30 per train-mile, would be

$$130 \times .0671\% \times 2 \times 365 = 63.68 \text{ c.}$$

For a round number we will call this 64 cents.

To forestall one kind of objection to the foregoing course of reasoning, it should be remembered that many of the estimates of additional cost, instead of being actually based on the effect of a continuous 10° curve, were based on the observed effects of lighter curvature, which were then multiplied by a factor to obtain the effect of a continuous 10° curve, as if the effects of curvature were strictly proportional to the curvature; but since we afterward divide our final result by 528 to obtain the effect of one

TABLE XXV.—EFFECT ON OPERATING EXPENSES OF CHANGES IN CURVATURE.

Item No.	Item (abbreviated).	Normal average.	Per cent affected.	Cost per mile, per cent.
1	Roadway........................	10.767	25	2.692
2	Rails...........................	1.422	326	4.636
3	Ties............................	2.948	50	1.474
4–10	Bridges, buildings, etc...........	5.897	0	0
	Maintenance of way.........	21.034	.....	8.802
11	Superintendence................	.617	0	0
12	Repairs, locomotives............	6.538	196	12.814
13	Repairs, passenger-cars..........	2.174	50	1.087
14	“ freight-cars.............	7.160	100	7.160
15	“ work-cars...............	.198	100	.198
16	Marine equipment................	.207	0	0
17	Shops..........................	.570	50	.285
18–19	Miscellaneous...................	.560	0	0
	Maintenance of equipment....	18.024	....	21.544
20	Superintendence................	1.757	0	0
21	Enginemen......................	9.607	0	0
22	Fuel............................	10.316	44	4.539
23	Water..........................	.647	44	.285
24	Oil, etc.........................	.377	44	.166
25	Other supplies..................	.202	44	.089
26–46	Train and station service, etc.....	33.730	0	0
	Conducting transportation....	56.636	....	5.079
47–53	General expenses................	4.306	0	0
		100.000	....	35.425

degree of curvature, and then multiply this constant by the number of degrees of central angle, as found in ordinary practice, our calculations are not thereby vitiated because the effect of curvature is not strictly proportional to the rate of curvature. It is probably true that within the ordinary limits of variations in rate of curvature the above calculations are substantially true. In extreme cases they are probably in error, although it is likewise probably true that extreme curvature will have a variable effect on the rate of increase of the various items, and that even in extreme cases the error will not be very large.

177. Numerical illustration.—In Fig. 31 is illustrated a case of a crooked line from which a considerable saving of curvature was made, although at a very large expenditure for earthwork, by eliminating the reverse curvature and all that part of the direct curvature which is necessary to balance the reversed curvature. This change of location was recently made by the Pennsylvaina Railroad, and involved not only the elimination of some very sharp curves, which prevented very high speed, but also eliminated about 494° of curvature and incidentally reduced the length of line by about 4700 feet. The total number of degrees of central angle in the original line is approximately 582, of which about 335° is in one direction and about 247° in the other. The new line therefore eliminates all of the curvature in one direction (247°), but likewise as much curvature in the other direction.

This problem also involves the reduction in the length of the line by about 4700 feet. The cost of this improvement was very great, since it involved the construction of four new bridges crossing the Conemaugh, and also some very heavy earthwork, four of the cuts having a depth at the highest point of 80, 105, 106, and 120 feet. The improvement was also combined with the widening of the road-bed for four tracks instead of two. On account of the very large amount of through competitive traffic hauled over the Pennsylvania lines, this reduction in distance is of benefit to the railroad to its full value on such traffic. It is not to be supposed that this reduction of 4700 feet in distance has the slightest effect in reducing the revenue received by the road.

In order to compute numerically the value and justification of the above improvement, it is necessary to know

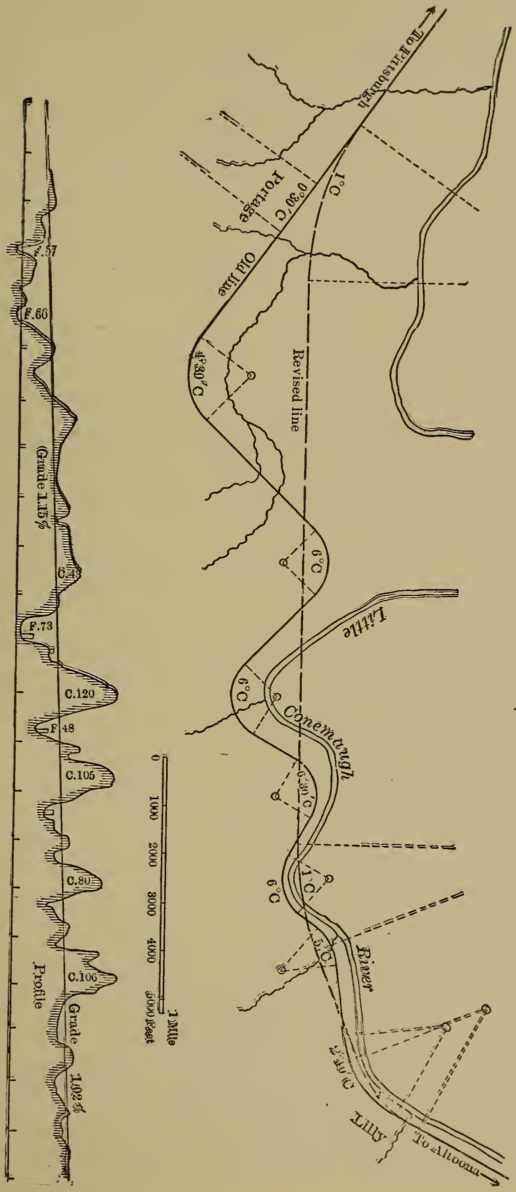


Fig. 31.—Revision of alinement, Pennsylvania Railroad between Portage and Lilly.

the number of trains actually using those tracks, and also the cost of the improvement. The determination of the number of trains is not easy, since the number of passenger-trains, which alone run by regular schedule, is but a small proportion of the total. The number of freight-trains is not even a constant quantity, since it varies from day to day with fluctuations of the traffic. The author has been unable to obtain any statement of the total number of trains on this division. Even the cost of the reduction of curvature and distance is so bound up with the cost of widening the road-bed for four tracks instead of two that it is impracticable to test, even by the above method, whether the improvements were justified. According to the curvature formula the saving on each regular train operating that stretch of track every day for one year would be

$$494^\circ \times 64 \text{ cents} = \$316.16.$$

The added saving per train per year on account of the reduction of distance would be

$$4700 \times 5.67 \text{ cents} = \$266.49.$$

The sum of these gives $582.65, the annual saving on each *regular* daily train. To allow for fluctuations, the *average* number of trains per day should be used as a multiplier. On the basis that this average number is 100, we have a computed annual saving of $58,265. Capitalized at 5%, this indicates a justifiable expenditure of $1,165,300.

If the original line in the above case had been constructed on a uniform grade, and if that grade had been the ruling grade, then since the new line is considerably shorter, the question of the grade of the new line would have been a very important one. In fact the improvement would have lost all of its value if its accomplishment had required an increase in the ruling grade of the road. But the new line has been put in with a ruling grade of 1.15% against east-bound traffic. Even this will doubtless be operated by pusher-engines for all heavy trains.

178. Reliability and value of the above estimate.—No extreme accuracy is claimed for the above method of estimating the effect of curvature. The effect of curvature depends on so many conditions, some of which are variable, that an estimate which might be mathematically perfect at one time would be somewhat altered during the succeeding year, on account of a change in operating conditions. Therefore the value obtained by any such calculations must be only considered as approximate. Nevertheless, it does give a value for the proposed change which is far better than a mere guess as to the desirability of an improvement. The real value of these figures may be tested as follows: If you vary some of the very important items very largely, it has a comparatively small influence on the final result. As an illustration, suppose that the item of renewals of rails is assumed to be affected 500% rather than 326%. The effect on the value of the reduction of 1° of curvature is increased less than 7%, which of course means that the justifiable expenditure to effect this result might and would be increased by the same percentage, but after all the real question is not whether the improvement in an ordinary case is worth, say, $10,000, or $10,700, seven per cent more. Possibly the extra work may be done for $3000 or it may require $25,000. In the first case there is but little question that the improvement will be justified in view of the probable growth in the business of the road. In the second case it would probably show that the improvement should be delayed until the amount of actual traffic will furnish a better justification for the work. If the estimated cost of the improvement very nearly equals the computed operating value of the change, the final decision on the question would depend very largely on the financial ability of the road to make such an improvement.

Compensation for Curvature.

179. Reasons for compensation.—When curvature and grade are combined on a track, the effect of the curvature is to increase the total resistance. This increase may be sufficient to have a material effect on the operation of trains. On minor grades the added resistance is of but little importance, since its virtual effect is the same as increasing the rate of grade somewhat; and if the virtual rate of grade which represents the sum of the two forms of resistance is still within the rate of the ruling grade, the net effect is merely to increase a few items of expense as given previously in this chapter. When the actual grade is nearly or quite equal to the ruling grade of the road, then the additional resistance caused by the curve will be the equivalent of a grade which is perhaps higher than the nominal ruling grade of the road. If we assume that the resistance on a 6° curve is 6 pounds per ton, which is the equivalent of the grade resistance on a 0.3% grade, then if a 6° curve were located on a 1% grade the resistance of a train on that grade would be practically the same as the resistance of that train on a 1.3% grade with straight track. If 1% grades were the ruling grades of that line and freight-trains were made up so that their engines would be taxed to the limit of their capacity on the 1% grade, then they would probably be stalled on the 6° curves, since the total resistance on those curves would be 30% higher than on the straight track having a 1% grade; but if the grade over these 6% curves is cut down to 0.7%, then the total resistance at such a point would still be equal to the resistance on a 1% grade with straight track. This effect can be illustrated by a diagram as in Fig. 32. Assume that a stretch of track consisting of alternate tangents and curves has an actual grade represented by the line *AN*. The angle between *BN* and *BC* represents the grade which is the equivalent of the added resistance caused by the curve *BC*. Then the tangent *CD* is drawn parallel to *AN*. Similarly the line *DE* makes an angle with *BN* equal to the equivalent grade resistance of the curve *DE*, and the angle of *DE* with the horizontal line represents a grade on which the resistance would be the equivalent of the total resistance on the curve *DE*, and then we have the line *EF* parallel to the line *BN*. The average resistance throughout that stretch of track would evidently be represented by the line *AF*, and therefore the angle *FAN* represents the grade which would cause a resistance equal to the *average* resistance actually caused by the curves. This figure therefore illustrates the fact that if the grade of a stretch of track, consisting of curves and tangents, is kept actually uniform, the *virtual* grade of that track is somewhat higher than the actual grade. If it becomes necessary for trains to stop on these curves, then the full effect of the resistance is encountered and the virtual grade would be as represented by the lines *BC* and *DE*. If it is possible to operate the trains throughout that stretch of track without any stops, then the virtual grade would be reduced approximately to the grade *AF*, since the trains would regain on

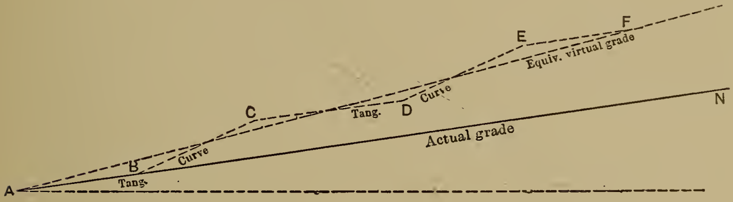


Fig. 32.—Effect of uncompensated curvature.

the tangents a portion of the energy which was lost on the curves.

If, on the other hand, the rate of grade is reduced on the curves, so that the actual grade is as shown by the line *ABCDEF* in Fig. 33, the reduction of the grade on the curves being just equal to the difference of grade which will represent the added resistance of the curves, then the virtual grade of the entire stretch of line will be as represented by the line *AG*.

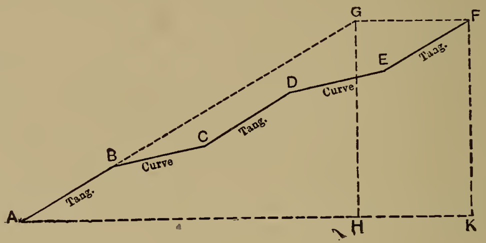


FIG. 33.—Grade virtually uniform, with compensated curves.

In laying out a ruling grade which is to carry a line to a summit, the compensation for curvature must unquestionably be provided, but it adds a complication which is also illustrated in Fig. 33. An engineer is frequently required to "develop" his line in order to have the necessary length for a given elevation to be overcome, in order that the grade shall be kept within some chosen limitation; but if the grades are actually reduced on the curves, the total horizontal distance required to overcome a vertical elevation of *HG* at the rate of grade shown by the tangent *AB* equals *AH*, but the distance actually required when the curves are compensated is something more, and is represented by the line *AK* in Fig. 33. The problem is further complicated, owing to the fact that the necessary additional distance can only be obtained by additional "development," which of itself usually implies additional curvature, and perhaps a great deal of it. In order to compensate this additional curvature there is required a still further increase in horizontal distance. The locating engineer therefore is confronted by the problem of introducing considerable added length of track and perhaps considerable added curvature, in order to obtain a ruling grade on which the resistance is virtually constant throughout, whether on a tangent or on a curve, and on which the maximum resistance does not exceed that of the chosen ruling grade for the line. Nevertheless, considering the supreme importance of avoiding an increase in the ruling grade (as will be developed later) and the comparative unimportance of an increase in distance or curvature, such a method is literally the only correct method to follow.

180. The proper rate of compensation.—This evidently is the rate of grade of which the resistance just equals the resistance due to the curve. Unfortunately for the simplicity of our calculations curve resistance is variable. It is greater for very low velocities. It depends somewhat on the detailed construction of the rolling-stock, although fortunately the differences in this respect are not great. When starting a train the curve resistance may amount to two pounds per ton per degree of curve. Such a resistance is equivalent to that encountered on a 0.1% grade. On this account the compensaton for a curve which occurs at a known stopping-place for the heaviest trains should be 0.1% per degree of curve. On the other hand, the compensation required for very fast trains may be as low as 0.02% or 0.03% per degree of curve. But these trains are not the trains which are usually limited by grade. It is the comparatively slow and heavy freight-trains which must be chiefly considered in the study of ruling grades. Therefore from 0.04% to 0.05% must be used as the rate of compensation for average conditions. Even these figures must be considered as only applicable to the ordinary and usual degrees of curvature.

It has been found that the resistance on the excessively sharp curvature used on street-railways or on elevated railroads is far less *per degree of curve* than the above figures would indicate. This is due to the fact that the actual resistance on a curved track is the sum of a number of resistances, some of which are virtually independent of the rate of curvature. Curves which occur immediately *below* a known stopping-place for *all* trains need not be compensated, for the extra resistance of the curve will reduce by that amount the work required from train-brakes in stopping the train. On the other hand, if a curve occurs just *above* a stopping-place it is a serious matter and should be amply compensated. In either case the down-grade traffic is not affected and therefore need not be considered. Although the suggested rate of compensation (0.04% or 0.05%) is possibly somewhat excessive, it has been recommended on the general principle that it is preferable that the compensation should be somewhat ample in order that it shall be sufficient for all cases. It is quite possible, however, that the excessive rate of compensation might require a steeper grade on the tangents, in order that the desired summit shall be reached in a given horizontal distance. In such cases the rate of compensation should be reduced to 0.035% or even 0.03%. Rules for compensation may therefore be stated as follows:

(1) On the upper side of a stopping-place for the heaviest trains compensate 0.10% per degree of curve.

(2) On the lower side of such a stopping-place do not compensate at all.

(3) Ordinarily compensate about 0.05% per degree of curve.

(4) Reduce this rate to 0.04% or even 0.03% per degree

of curve, if the grade on the tangents must be increased in order to reach the required summit.

(5) Reduce the rate somewhat for curvature above 8° or 10°.

(6) Curves on minor grades need not be compensated, unless the minor grade is so heavy that the added resistance of the curve would make the total resistance greater than that of the ruling grade.

181. The limitations of maximum curvature.—What is the maximum degree of the curvature which should be allowed on any road? Unquestionably there is no definite limit. If any limitation is made it depends on the general character of the country and on the amount of traffic which may be immediately expected. As an extreme case in the justifiable use of sharp curvature, we may consider a portion of the line from Denver to Leadville, Colo. The traffic that was expected on the line was so meager, and the general character of the country was so forbidding, that a road built according to the usual standards would have cost very much more than would have been justified by the expected traffic. The lines as adopted cost about $20,000 per mile, and yet in a stretch of 11.2 miles there are about 127 curves. One is a 25° 20′ curve, 24 are 24° curves, 25 are 20° curves, and 72 are sharper than 10°. If 10° had been made the limit (a rather high limit according to usual ideas), it is probable that the line would have been found impracticable (except with prohibitive grades), unless four or five times as much per mile had been spent on it, and this would have ruined the project financially.

As an illustration of the other extreme, we may consider some of the improvements which have been recently made on the P. R.R. between Philadelphia and Pittsburg. Millions of money have been spent in the effort to reduce distance, curvature, and grade. The reduction of curvature has been very largely in the form of eliminating degrees of central angle, but it also has taken the form of increasing the radius of curvature, so that the running of express-trains at a speed of 60 miles per hour will be facilitated. This is one of the comparatively rare cases where an increase in the radius of curvature justifies a considerable expenditure.

Another illustration of the use of sharp curvature by a line of heavy traffic is given by the case of the B. & O. R.R. in its line at Harper's Ferry. For many years the traffic of this road passed over two curves, one with a radius of 300 feet (19° 10′) and then over a 400-foot curve (14° 22′). During recent years this sharp curvature has been materially reduced by means of some very expensive tunneling, but the fact that the engineers of this line very wisely concluded to run the traffic of a great trunk line over such sharp curves shows how foolish it is for an engineer to sacrifice money or sacrifice gradients in order to reduce the rate of curvature on a road which at its best will be a line of very small traffic. Many locating engineers have started out to locate a line with instructions that their maximum rate of curvature must not exceed 6°. Possibly it would be better to say that no limitation should be imposed. It is far better to operate a road on a 10° or 15° curve in some one place, provided that the cost of avoiding such a curve will be very large. This is especially true for the light-traffic roads, which constitute such a large proportion of our mileage, and which will probably constitute the great bulk of the roads yet to be constructed. Of course such belittling of the effects of curvature may be, and sometimes is, carried to an extreme and cause an engineer to fail to give to curvature its due consideration. Degrees of central angle should always be reduced by all the ingenuity of the engineer, and should only be limited by the general relation between the financial and topographical conditions of the problem. Easy curvature is in general better than sharp curvature and should be adopted when it may be done at a small financial sacrifice, especially since it reduces the length of the line. Nevertheless the engineer should not give undue prominence to curvature in comparison with the other features of alinement, which are really of far greater importance. He should remember that so far as the cost of track-work is concerned, there is little if any saving in this respect, and that the extra cost of operating trains on curves is very nearly independent of the radius of curvature. Of course the trains cannot be operated at high speed on sharp curves, but if the road is a minor road such a condition will have almost no effect on the operation of trains. Above all, the engineer should not waste the capital of the road (which is usually limited) in an effort to avoid curvature, when any spare funds may more profitably be expended in making reductions of grade which will be of vastly greater financial value.

CHAPTER XIV.

MINOR GRADES.

182. Two distinct effects of grade. — The effects of grade on train expenses are of two distinct kinds. One possible effect is very costly and should be limited even at considerable expenditure. The other is of comparatively little importance, its cost being slight. As long as the length of a train is not limited by the power of the engine, the occurrence of a grade on a road merely means that the engine is required to develop so many foot-pounds of work in raising the train so many feet of vertical height. For example, if a train weighing 600 tons (1,200,000 pounds) climbs a hill 50 feet in height, the engine performs, in addition to the work due to merc tractive resistance and curvature, the extra work of creating 60,000,000 foot-pounds of potential energy. If this height is surmounted in two miles of horizontal distance (grade of 25 feet per mile) and in six minutes of actual time (20 miles per hour), the *extra* work accomplished by the engine is done at the rate of 10,000,000 foot-pounds per minute, which is about 303 horse-power. But the disadvantages of such a rise are always largely compensated. Except for the fact that one terminus of a road may be higher than the other, every up grade is followed more or less directly by a down grade, which is operated partly by the potential energy acquired during the previous climb. But when we consider the trains running in both directions, even the difference of elevation of the termini is largely neutralized. If we could eliminate altogether the waste of energy in the use of brakes, where brakes are used to control the train on grades, we would then find that the *net* effect of minor grades on either operation in both directions would be zero. Whatever was lost on any up grade would be regained on the succeeding down grade or on the return trip. On the very lowest grades, the limits of which are defined later, we may consider this to be literally true, viz., that nothing is lost by their presence. It is unnecessary to use brakes on these grades, except for such use as would be made if the line were level. Whatever energy is temporarily lost in climbing any grade is either immediately regained on a subsequent down grade or is regained on the return trip.

The other effect of grade is that it may so limit the length of trains that more trains will be required to handle a given traffic. The receipts from traffic are a perfectly definite sum which is independent of the number of trains. The cost of handling the traffic will be nearly proportional to the number of trains. Anticipating a more complete discussion, it may be said, as an example, that increasing the ruling grade from 1.20% (63.36 feet per mile) to 1.55% (81.84 feet per mile—an increase of about 18.5 feet per mile) will be sufficient to increase the required number of trains for a given gross traffic about 25%, i.e., five trains will be required to handle the traffic which four trains would have handled before at a cost slightly more than four-fifths as much. Since the gross receipts remain the same and the operating expenses have been increased nearly 20%, the effect on dividends is readily imagined. On the other hand, a reduction of the grade, which will enable four trains to handle an amount of traffic which have required five trains on the heavier grade, will have a corresponding influence in decreasing the operating expenses and will justify a large expenditure to accomplish this result.

183. Basis of the cost of minor grades.—The basis of the computation of this least objectionable form of grade is as follows: The resistance to the movement of a train on a straight level track is variable, depending on the velocity, the number and character of the cars, and on the character of the road-bed and track. No one figure that can be stated may be considered accurate for all cases, but for average conditions and for average velocities we may consider that the round number of 10 pounds per ton is a reasonable figure. This value agrees fairly well with the results of some dynamometer tests made by Mr. P. H. Dudley, using a passenger-train of 313 tons running at about 50 miles per hour. It also agrees with Searles's formula (based on experiments) for the resistance of a freight-train with 40 cars running 25 miles per hour. Using the very approximate resistance formula published by the "Engineering News," which makes the resistance in pounds per ton equal to $\left(2+\frac{V}{4}\right)$, in which V is the velocity in miles per hour, this value would be true for a train moving at a speed of 32 miles per hour. A comparison of the three cases mentioned above shows at once the wide variations in the values given by different formulæ. Therefore this value of 10 pounds per ton may be considered to be as nearly correct for an average value as any other one value that can be chosen. Ten pounds per ton is the grade resistance of a 0.5% grade, or a grade of 26.4 feet per mile. On this basis a 0.5% grade will just double the tractive resistance on a straight level track. We may compute, as in the previous chapter, the cost of doubling the tractive resistance for one mile, but, since the extra resistance is due to lifting the train through 26.4 feet of elevation, we may divide the extra cost of a mile of 0.5% grade by 26.4 and we will have the cost of *one* foot of difference of elevation. If the rate of grade is not so great that it has an effect in limiting the length of trains, we may then say that the cost of this one foot of difference of elevation is independent of the rate of grade. On account of the compensating character of the effect of grade in the operation of trains down the grade or in the operation of a train down the other side of an elevation which has just been climbed, we must consider the total effect of one foot of *rise* and *fall*. Although we may say in a general way that the cost of one foot of rise and fall is independent of the rate of grade, it is true, as will be seen, that the cost of a foot of rise and fall of a very light grade is very much less than the cost of a foot of a much heavier grade.

184. Meaning of "rise and fall."—In the simplest case a rise and fall of so many feet means a rise from the starting-point to a summit and a return to the same level, as is shown in Fig. 34. For instance, in Fig. 34 (a) is indicated a rise and fall of BD above the level AC, but (b) and (c) may be considered just as much cases of rise and fall. In (c) the line AB is actually an up grade, and yet we may consider it as a virtual drop. If a freight-train is moving up the grade in (b) and the engine is doing the work which will carry it steadily up the grade ADC, it encounters additional resistance on the extra grade AB, and must either work much harder or it will continue to lose velocity. If it has sufficient momentum to carry it over the point B it will then continue on the grade BC, which, although an up grade, is so much less than the grade DC that the engine will do more work than is required on such a grade and hence will gain velocity. This is essentially the same case as though a train were moving uniformly along the level (case a) and encountered the hump ABC. The case is essentially the same in (c).

Although *AB* is actually an up grade, it is so much less than the grade *ADC* that if a train were running up that grade with the engine doing an amount of work which would carry it uniformly up the grade *ADC*, the resistance on the lesser grade *AB* will be so much less that the train will actually gain velocity and acquire a momentum which will enable it to climb the still steeper grade *BC*, so that by the time it reaches *C* it will have practically the same velocity which it had at *A*. We are therefore justified in considering that whether the train passes over a hump which is superimposed on an otherwise uniform grade, whether level or not, or goes through a sag which occurs in what would otherwise be a uniform grade, we may consider that in all cases the train is encountering what we denominate as "rise and fall." When the line runs through a stretch of several miles with very light grades, all of which are well within the ruling grade. there is in general no possibility of doing anything which will

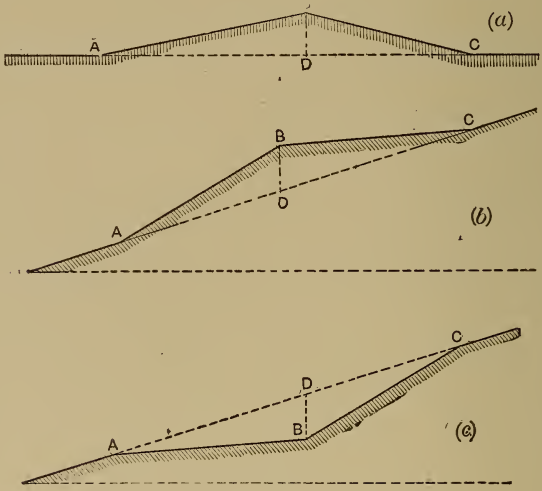


Fig. 34.—Types of "rise and fall".

favorably affect the grade. Practically all that we can do is to remove what is virtually a hump or a sag in what is otherwise a nearly uniform grade or level.

185. Classification of minor grades. — The additional cost of one foot of rise and fall is not altogether independent of the rate of grade. We can, however, divide grades into three groups, within which we may say that the cost of a foot of rise and fall is practically uniform. In the first class are grades which may be operated without changing the work of the engine, and which have practically no other effect than a harmless fluctuation of the velocity, but a grade which belongs to this class, when considering a fast passenger-train, will belong to another class when considering a slow and heavy freight-train, and, since it is the slow and heavy freight-trains which must be chiefly considered, a grade will usually be classified with respect to them. The limit of class *A* therefore depends on the maximum allowable speed, and also depends on the length of the grade and the depth of the sag. If it is permissible to operate all trains through the sag without making any change in the handling of the engine, without changing the throttle-valve or the position of the links, and especially without the use of brakes, then the effect of the sag on the operation of trains is possibly zero, and the sag or hump has no financial importance. The above conditions assume that the engine is working uniformly throughout, that all potential energy which is lost on the steeper grade is regained on the lighter grade. In the case of a sag the change in potential energy merely comes in reversed order. If train resistance and tractive effort were actually independent of velocity, the assumption that class *A* has no influence on train expenses would be almost theoretically precise. The operation of momentum grades has been considered in Chapter XI. In classifying a sag or a hump we must therefore consider whether trains which run over or through it may be operated without changing any operating conditions. We will very often discover that passenger-trains may be so operated, while freight-trains will need to be handled differently. Therefore such a hump or sag will be classified as belonging to class *A* for passenger-trains, and to class *B* or possibly class *C* for freight-trains.

The next classification (*B*) applies to grades on which a change of operating conditions becomes necessary. On the down grade it becomes necessary to partially, if not entirely, close the throttle, in order that the velocity shall not become too great. On the other hand, the up grade is so steep that the engine must work considerably harder, consume more coal, and perhaps operate with a longer cut-off and therefore less economy than is possible on the lighter grades. As long as brakes are not used there is no actual loss of energy, except that steam will probably be wasted by being blown through the safety-valve while the train is running down the grade with the throttle closed. The chief disadvantage is due to the uneconomical working of the train on the heavier up grade. On the down grade the losses in fuel consumption, due to radiation, etc., will become a much larger percentage than usual of the useful work actually obtained from the engine.

The third class (*C*) includes humps which are so high and sags which are so deep that brakes must be applied on the down grade in order to prevent excessive velocity. The loss by the application of brakes is very heavy. The brakes require power for their application which is a considerable tax on the locomotive. The use of brakes cauess wear of the brake-shoes and of the wheel-tires, which hastens the deterioration of the rolling-stock. Their use destroys the kinetic or potential energy which had previously been created, while the tax on the locomotive on the corresponding ascending grade is very great.

It may be seen that the classification of these humps and sags is more a matter of the total height of the hump or the depth of the sag rather than the rate of grade. The sag or hump which has a comparatively steep grade on both sides may be almost harmless if the grades are short, or (which amounts to the same thing) if the height or depth is small. On the other hand, a comparatively light grade may become of importance because it is so deep. It is not usual, however, that a sag or hump could be classified in class *C* if the grade is very light, since it requires a considerable grade to cause a train to attain a dangerous velocity when the steam is turned off. Excessively long sags or humps are practically outside of the line of problems which may thus be considered.

186. Effect on operating expenses.—As in the previous chapter we may at once throw out a large proportion of the items of expense of an average train-mile. In "maintenance of way and structures" Items 4 to 10 are evidently unaffected. The other items will be variously affected according to the classification of grades.

187. Item 1. Repairs of roadway.—It is very plain that a large proportion of the subitems are absolutely unaffected by minor grades. In fact it is a little difficult to ascribe any definite increase to any subitem. Rail wear is somewhat increased and this will have some effect in increasing the track-work. Wellington allows 5% increase as a liberal estimate for class *C*, and makes no allowance for classes *A* and *B*.

188. Item 2. Renewals of rails.—Observations of rail wear on heavy grades show that the wear is much greater than on level tangents. The heavy grades of a mountain division of a road are usually operated with shorter trains or with the help of pusher-engines, and in such cases the proportion of engine tonnage to the total is much greater than on minor grades, and, since the engine has much greater effect on rail wear than an equal total tonnage of cars, partly on account of the use of sand and excess of engine tonnage, the grade will have a marked effect on rail wear. But such circumstances apply to ruling grades and very little, if at all, to minor grades. The use of sand on up grades and the possible skidding of wheels on down grades will wear the rails considerably. Even the slipping of the drivers, although sand is not used, will wear the rails. Wellington allows 10% increase for class *C* and 5% for class *B*.

189. Item 3. Renewals of ties.—The extra wear of ties on grades is considered by Wellington as being somewhat compensated by the improved drainage of the road-bed which is found on a track which is not quite level, the better drainage tending to increase the life of the ties. On this account Wellington made an allowance of 5% increase for class *C* and no increase for the other classes.

190. Maintenance of equipment.—It is evident that none of these items will be affected except Items 12 to 15, "the repairs and renewals of engines and cars." The chief effect on these items will evidently be the repairs and renewals of wheels and brake-shoes. The draw-bars are also apt to suffer somewhat, on account of the increased work which they are required to do. It would appear that the extra stress on the locomotive mechanism will have some effect on locomotive repairs, and the expense of boiler repairs may be increased on account of the greater range of the demands on it. It would seem as if such effects would be quite large, but if the records of engine and car repairs on mountain divisions and on comparatively level divisions of the same road are examined and compared, there appears to be no such difference as might be expected. Considering the very small proportion of locomotive and car repairs which are affected at all by such circumstances, and also the very small percentage of these subitems which can be said to be affected by these two classes of minor grades, Wellington allows only an increase of 4% on each of these four items for class *C* and 1% for class *B*.

191. Conducting transportation.—It is apparent that the only items in conducting transportation which will be affected will be the four items of engine-supplies (22 to 25). As in Chapter XIII, since we are considering that the resistance is doubled, we will assume that there is an increase of 44% as the cost of the extra fuel used in climbing 26.4 feet, but the total cost of both rise and fall is to be considered. In class *B*, although steam is shut off, fuel will be wasted by mere radiation. On this account we will add 5%. For class *C* we must allow in addition the energy spent in applying the brakes, which we may assume as 5% more. Therefore we will allow 49% for class *B* and 54% for class *C*. The other small items of supplies, 23, 24, and 25, will be estimated similarly. The items of general expense are evidently unaffected.

192. Estimate of cost of one foot of change of elevation.—Collecting the above estimates we have Table XXVI, showing that the percentage of *increase* for operating grades of classes *B* or *C* will be 5.89% and 7.70% respectively of the average cost of a train-mile. On the basis of an average cost of $1.30 per train-mile, the additional cost for the 26.4 feet of rise and fall in one mile would be 7.66 c. and 10.01 c., or 0.29 c. and 0.38 c. per foot for the two classes respectively. For each train per day each way per year the value per foot of difference of elevation is

For class B: $2\times 365\times \$0.0029=\$2.12$.
" " C: $2\times 365\times \$0.0038=\$2.77$.

In assuming the number of trains running over a given grade the character of the trains must be carefully considered, since it will quite frequently happen that a hump or sag must be classified as belonging to class *C*, so far as heavy freight-trains are concerned, but may be classified as *B* or perhaps even *A*, the harmless class, for passenger-trains. The above values should likewise be modified when the trains are run only 313 days per year instead of 365.

TABLE XXVI.—EFFECT ON OPERATING EXPENSES OF 26.4 FEET OF RISE AND FALL.

No.	Item (abbreviated).	Normal average.	Class B.		Class C.	
			Per cent affected.	Cost per mile.	Per cent affected.	Cost per mile.
1	Roadway.	10.767	0	0	5	.538
2	Rails.	1.422	5	.071	10	.142
3	Ties.	2.948	0	0	5	.147
4–10	Bridges, buildings, etc.	5.897	0	0	0	0
	Maintenance of way.	21.034	. .	.071	. . .	.827
11	Superintendence.	.617	0	0	0	0
12	Repairs, locomotives.	6.538	1	.065	4	.261
13	Repairs, passenger-cars.	2.174	1	.022	4	.087
14	Repairs, freight-cars.	7.160	1	.072	4	.286
15	" work-cars.	.198	1	.002	4	.008
16–19	Miscellaneous.	1.337	0	0	0	0
	Maintenance of equipment. . .	18.024	. . .	.161	. . .	.642
20	Superintendence.	1.757	0	0	0	0
21	Enginemen.	9.607	0	0	0	0
22	Fuel.	10.316	49	5.055	54	5.571
23–25	Water, oil, etc.	1.226	49	.601	54	.662
26–46	Train-service, etc.	33.730	0	0	0	0
	Conducting transportation. . .	56.636	. . .	5.656	. . .	6.233
47–53	General expenses.	4.306	0	0	0	0
		100.000	. . .	5.888	. . .	7.702

193. Numerical illustration.—Assume that the grade of a railroad in crossing a river valley includes a sag 5000 feet long and with a depth in the center of 40 feet. Assume that freight-trains would ordinarily approach this sag at a velocity of 20 miles per hour. The velocity head at 20 miles per hour, as found in Table XX, is 14.05 feet. Adding the depth of the sag, 40 feet, we would have the velocity head at the bottom of the sag, 54.05 feet, which corresponds to a velocity of over 39 miles per hour. The extensive adoption of automatic couplers and train-brakes have permitted the use of much higher freight-train speeds than were permissible some years ago. Even though it might be considered safe to run the train through the sag at a speed of nearly 40 miles per hour, it is unquestionable that a freight-engine could not develop steam fast enough to exert a *constant* draw-bar pull up to a speed of 39 miles per hour. There would therefore be a very considerable loss from the theoretical operation of such a sag as described above, and we must consider that the sag will not belong to class (A), at least for freight-trains. If a passenger-train approached this sag at a velocity of 30 miles per hour, the velocity head then being 31.60 feet, its velocity head at the bottom of the sag would be 71.60, which would correspond to a velocity of over 45 miles per hour. If the passenger-engine were so lightly loaded that its draw-bar pull at the top of the sag was quite small, and its boiler capacity was so large that it could develop this light draw-bar pull even at a speed of 45 miles per hour, then for such trains we could consider the sag as belonging to class (A), the harmless class. Assume that after an analysis of the character of the trains using the sag, we find there are six trains per day each way in the operation of which the sag should be classed as class (C), and eight other trains per day each way for which it should be classed as class (B). It should be noted that it is not essential to fill up the sag altogether and make it level. If we fill up only the lower 20 feet, which will not ordinarily cost more than one-fourth to one-third as much as filling up the upper 20 feet, the sag would probably become harmless for all classes of trains. We will therefore compute the value of reducing the depth of the sag 20 feet. We will have the added cost of operating this 20 feet as follows:

Eight trains, class (*B*): $8 \times 20 \times \$2.12 = \$339.20$
Six " " (*C*): $6 \times 20 \times \$2.77 = \$332.40$
Total annual saving. $671.60

Capitalizing this at 5%, we have $13,432 as the justifiable expenditure to fill up the lower 20 feet of this sag. Of course the amount of earthwork required to make this fill can be readily computed. In the case of a new road we would have merely this additional cost to the original plan of construction. If such a plan is considered with the intention of improving an old line, the cost of raising the track, and all the added expense involved in maintaining the track so that traffic may continue to run over it, will have to be added as part of the cost of improvement. The cost of such an improvement is a comparatively simple matter to determine. The above demonstration, even though it is based on data which is approximate, is at least a measure of the value of the improvement, which is far better than having no measure at all. In applying the method outlined above to any particular case, the problem must be studied from the beginning with reference to all the available figures of cost as applied to the given road. The figures given above for the value of one foot of rise and fall of either class should not be used in general for all cases, and in fact should never be used except as an approximate method for computing the value of a change in the proposed location of a new road where there is no data on which to base more accurate calculations.

CHAPTER XV.

RULING GRADES.

194. Definition.—Ruling grades are those which limit the weight or length of a train of cars which may be hauled by one engine. They are frequently, although not necessarily, the steepest grades on the road. It is sometimes possible by a mere change in the method of operating the trains to very greatly reduce what must technically be considered the ruling grade of the road. When one or two grades on the road are considerably higher than all other grades, it is possible to use assistant engines on those grades, and thereby very greatly increase the weight or number of cars in a through-train load over the entire line. The weight of train will then be limited by the next lower grade, which may be a grade which offers but little more than one-half the total resistance of the grade which is operated by pusher-engines. This enables the train-load to be practically doubled. Such grades, which are called pusher grades, will be considered in a succeeding chapter.

When a grade is very short and it is never necessary to stop a train while on the grade, it is frequently possible to load up an engine with a far greater number of cars than could be run up an indefinite grade of that length. This has already been discussed in the chapter on Momentum Grades. These are the most common exceptions to the general statement that the ruling grade is usually the maximum grade of the road.

The selection of the general route of the road usually determines more or less definitely the ruling grade of the road, except as that may be modified by "development." The rate of ruling grade should bear some relation to the general character of the road which is to be built. A second-class or third-class road, which at its best will never be anything more than a branch line, is not justified in spending much money to reduce a ruling grade. On the other hand, a great trunk line is thoroughly justified in spending enormous sums in the construction of tunnels, deep cuts, high embankments or viaducts, in order to reduce the rate of the ruling grade. In this chapter we will endeavor to determine the financial relation between the lowest permissible grade and the money which may profitably be spent to secure it.

195. Choice of ruling grade.—A little consideration regarding the practical operation of trains will show that it is impracticable for an engine to drop off or pick up cars in accordance with the grades which may be encountered along the line. The nearest approach to this is to divide a long road into divisions. At the termini of each division are located freight-yards at which the cars are assorted, and, if necessary, the train-load is increased or diminished, according to the capacity of the engines which are to haul the trains over the succeeding division. The locating engineer cannot determine the proper rate of ruling grade for a line until after the belt of country through which the road is to pass has been thoroughly surveyed, and he can study the project as a whole. There are usually a dozen or more points within a distance of 100 miles through which a railroad is almost compelled to pass, and which must be considered as governing points, unless there is very urgent reason why the road should not go through them. The selection of the rate of grade then becomes a problem of determining the best route between each pair of consecutive governing points. If the natural grade between two consecutive points is very high, and much higher than the grades between other consecutive ruling points, it may be advisable to immediately decide to operate the especially steep grade with pusher-engines, and thereby make it possible to use a much lower rate for the ruling grade. The endeavor should be made to cut down all grades which would naturally be somewhat higher than the other grades until a considerable number of grades have been determined, all of which are approximately equal and which cannot be materially reduced without a large expenditure. On the one hand, it will not pay to spend any amount of money to reduce a grade below this maximum which has been selected, although, on the other hand, it will pay to spend considerable to cut down the rate of grade on one or two grades which are higher than the general maximum. In this way may be determined, after considerable study, some limit of grade which can be used at all points without an extravagant expenditure of money, and yet which could not be reduced, on account of the large number and length of the grades which would be involved, without an extravagant expenditure of money. The engineer is frequently confronted with a definite problem substantially as follows: The rate of ruling grade at one or two places on the line is naturally at some definite figure, say, 1.4%. By spending an easily computable sum of money the line may be modified so that the ruling grade is reduced to perhaps 1.0%. The engineer must then consider the traffic to be run over the road, and must compute the effect on the operating expenses of reducing the rate of grade. If the annual saving in operating expenses, when capitalized, materially exceeds the cost of obtaining the lower grades, it will probably be justifiable to construct them.

196. Maximum train-load on any grade.—The tractive power of a locomotive, and especially the reduction of the effective tractive power with increase in velocity, has already been discussed in previous chapters. It is expected that on ruling grades a train runs slowly if necessary. Fortunately the tractive power of a locomotive is greatest when the speed is slow, and when very nearly the full theoretical adhesion of the drivers to the rails can be counted on. In Table XXVII are given the tractive powers of locomotives of a wide range of types and weights and with various ratios of adhesion. Almost any locomotive will be sufficiently similar to one of these given in this table, so that the tractive force here given may be used for calculations, at least approximately. In Table XXVIII is shown the total train resistance in pounds per ton for various grades and for various values of track resistance. By a combination of these two tables the net train-load on any grade under given conditions may be quickly determined. For example, a consolidation engine, weighing 214,000 pounds and having 106,000 on the drivers, will have a tractive power of 26,500 pounds when the effective adhesion is $\frac{1}{4}$. When it is moving slowly up a 1.2% grade the grade resistance is 24 pounds per ton, and if the tractive resistance on a level is 6 pounds per

TABLE XXVII.—TRACTIVE POWER OF VARIOUS TYPES OF STANDARD-GAUGE LOCOMOTIVES AT VARIOUS RATES OF ADHESION.

Type of Locomotive.	Total weight of engine and tender.		Weight of engine only.	Weight on the drivers.	Tractive power when ratio of adhesion is		
	Lbs.	Tons.			1/4	9/40	1/5
Atlantic, 4–4–2.	340,000	170.0	199,400	105,540	26,385	23,740	21,100
Atlantic, 4–4–2, four-cylinder compound.	368,800	184.4	206,000	115,000	28,750	25,875	23,000
Pacific, 4–6–2	343,600	171.8	218,000	142,000	35,500	31,950	28,400
Pacific, 4–6–2	403,780	201.9	226,700	151,900	37,975	34,180	30,380
Ten-wheel, 4–6–0.	321,000	160.5	201,000	154,000	38,500	34,650	30,800
Prairie, 2–6–2.	366,500	183.2	212,500	154,000	38,500	34,650	30,800
Consolidation, 2–8–0	214,000	107.0	120,000	106,000	26,500	23,850	21,200
Consolidation, 2–8–0	366,700	183.3	221,500	197,500	49,375	44,440	39,500
Mikado, 2–8–2.	405,500	202.7	259,000	196,000	49,000	44,100	39,200

ton the total train resistance per ton will be 30 pounds. Dividing 26,500 by 30, we have 883 pounds as the gross train-load. Subtracting 107 tons, the weight of the engine and tender in working order, we will have 776 tons as the net load. A much better way of considering this will be on the basis of rating tons, as already explained in Chapter XI, but, whatever the method adopted, Tables XXVII and XXVIII are accurate as long as the velocity is so slow that the boiler capacity is not overtaxed, and as long as the proper ratio of adhesion and the actual tractive resistance on a level are chosen for use in the tables.

197. Proportion of traffic affected by the ruling grade. —Very many light-traffic roads are not fortunate enough to have a traffic which is materially affected by the rate of ruling grade. Passenger-trains are very seldom affected, unless the volume of traffic is so great that the number of cars attached to one engine approaches the limit which one engine is able to haul. The comparatively high speed usually demanded of passenger-trains means that the locomotive must have high steaming power to haul even light loads. Such light loads do not require very great tractive force, and therefore the tax on the adhesion of the drivers is correspondingly small. When a passenger-train reaches an unusually heavy grade, the effect of the grade is usually confined to reducing the speed of the train. On any road but a trunk line such a slight reduction of speed has almost no financial value. We may therefore make the general statement that for all light-traffic roads the passenger-trains need not be considered as being affected by the rate of ruling grade. Local freight-trains may sometimes be considered in the same way. It frequently happens that the local freight is sent out over the line with a far less number of cars than *could* be hauled by one engine, and therefore the ruling grades cannot be considered as affecting these trains. Whatever

TABLE XXVIII.—TOTAL TRAIN RESISTANCE PER TON (OF 2000 POUNDS) ON VARIOUS GRADES.

Grade.		When tractive resistance *on a level* in pounds per ton is					Grade.		When tractive resistance *on a level* in pounds per ton is				
Rate per cent.	Feet per mile.	6	7	8	9	10	Rate per cent.	Feet per mile.	6	7	8	9	10
0.00	0.00	6	7	8	9	10	2.00	105.60	46	47	48	49	50
.05	2.64	7	8	9	10	11	.05	108.24	47	48	49	50	51
.10	5.28	8	9	10	11	12	.10	110.88	48	49	50	51	52
.15	7.92	9	10	11	12	13	.15	113.52	49	50	51	52	53
.20	10.56	10	11	12	13	14	.20	116.16	50	51	52	53	54
0.25	13.20	11	12	13	14	15	2.25	118.80	51	52	53	54	55
.30	15.84	12	13	14	15	16	.30	121.44	52	53	54	55	56
.35	18.48	13	14	15	16	17	.35	124.08	53	54	55	56	57
.40	21.12	14	15	16	17	18	.40	126.72	54	55	56	57	58
.45	23.76	15	16	17	18	19	.45	129.36	55	56	57	58	59
0.50	26.40	16	17	18	19	20	2.50	132.00	56	57	58	59	60
.55	29.04	17	18	19	20	21	.55	134.64	57	58	59	60	61
.60	31.68	18	19	20	21	22	.60	137.28	58	59	60	61	62
.65	34.32	19	20	21	22	23	.65	139.92	59	60	61	62	63
.70	36.96	20	21	22	23	24	.70	142.56	60	61	62	63	64
0.75	39.60	21	22	23	24	25	2.75	145.20	61	62	63	64	65
.80	42.24	22	23	24	25	26	.80	147.84	62	63	64	65	66
.85	44.88	23	24	25	26	27	.85	150.48	63	64	65	66	67
.90	47.52	24	25	26	27	28	.90	153.12	64	65	66	67	68
0.95	50.16	25	26	27	28	29	.95	155.76	65	66	67	68	69
1.00	52.80	26	27	28	29	30	3.00	158.40	66	67	68	69	70
.05	55.44	27	28	29	30	31	.05	161.04	67	68	69	70	71
.10	58.08	28	29	30	31	32	.10	163.68	68	69	70	71	72
.15	60.72	29	30	31	32	33	.15	166.32	69	70	71	72	73
.20	63.36	30	31	32	33	34	.20	168.96	70	71	72	73	74
1.25	66.00	31	32	33	34	35	3.25	171.60	71	72	73	74	75
.30	68.64	32	33	34	35	36	.30	174.24	72	73	74	75	76
.35	71.28	33	34	35	36	37	.35	176.88	73	74	75	76	77
.40	73.92	34	35	36	37	38	.40	179.52	74	75	76	77	78
.45	76.56	35	36	37	38	39	.45	182.16	75	76	77	78	79
1.50	79.20	36	37	38	39	40	3.50	184.80	76	77	78	79	80
.55	81.84	37	38	39	40	41	4.00	211.20	86	87	88	89	90
.60	84.48	38	39	40	41	42	4.50	237.60	96	97	98	99	100
.65	87.12	39	40	41	42	43	5.00	264.00	106	107	108	109	110
.70	89.76	40	41	42	43	44	5.50	290.40	116	117	118	119	120
1.75	92.40	41	42	43	44	45	6.00	316.80	126	127	128	129	130
.80	95.04	42	43	44	45	46	6.50	343.20	136	137	138	139	140
.85	97.68	43	44	45	46	47	7.00	369.60	146	147	148	149	150
.90	100.32	44	45	46	47	48	8.00	422.40	166	167	168	169	170
1.95	102.96	45	46	47	48	49	9.00	475.20	186	187	188	189	190
2.00	105.60	46	47	48	49	50	10.00	528.00	206	207	208	209	210

business is done by the road in handling bulky freight, such as coal, ore, or timber, is usually handled in train-loads which are made as heavy as the power of the engine on the grades of the road will permit. All such trains are directly affected by the rate of ruling grade. Therefore, in counting the number of trains which are affected by the ruling grade, we must usually count all coal-, lumber-, and ore-trains, and all through freight-trains which are run from one terminus of the division to another, as well as passenger-trains, if any, which are actually limited in length or weight by the grade.

198. Financial value of increasing the train-load.— The gross receipts obtained for transporting a given amount of freight is a definite sum which is independent of the number of train-loads required to handle it. On the other hand, the cost of a train-mile is nearly constant. If it were actually so, we could say at once that the cost of handling the traffic would be proportional to the number of trains, and that the saving of even one train-load, or of handling in four trains what would otherwise require five train-loads, would reduce the operating expenses proportionally. The problem is a very similar one to that already worked out in Chapter VII, but with a very important difference in some of the conditions. In both cases the object to be gained is the reduction in the number of trains to handle a given gross tonnage of freight traffic In the case worked out in Chapter VII, this is accomplished by merely increasing the power of the locomotives, so that a given amount of traffic can be handled in three trains instead of four, or in six trains instead of seven, the grades of the road being the same in each case. By the method discussed in this chapter, the grade is so reduced that an engine of given type may haul a larger number of cars, and therefore a certain gross amount of freight tonnage can be handled in three trains instead of four, or in six trains instead of seven, using engines of the same type and weight. In the first case, the power of the engine is increased; in the second case, the demand on its capacity is reduced by a reduction in the grade.

We will estimate as before the difference in the cost of operating, say, four light trains on heavy grades, or three heavier trains on the lighter grades. In either case the gross tonnage of cars, with their contents, is supposed to be the same. The difference consists in the cost of operating the extra engine and also the extra cost for train service, etc., which is a function of the number of trains on the road rather than of their tonnage. For the same reasons as are given in detail in § 86, we will consider that the items in maintenance of way will be affected the same as is there computed, namely, 3.531%.

199. Maintenance of equipment.—We will consider that Item 11 is unaffected. While there is some ground for considering that using four engines instead of three for a given gross tonnage of freight is actually somewhat of an advantage in some respects, since it reduces the work of the locomotive throughout the level sections of road, it is not safe to allow very much on this account. If, on account of the reduction in average draw-bar pull, the repairs of each of four locomotives were reduced 5% below the repairs of the three locomotives which could haul the same number of cars over lower ruling grades, then the repairs of the four locomotives would cost 4×95, or 380 compared with 3×100, or 300 for the three locomotives. This would mean that the additional locomotive should be assigned an added expenditure of 80% of the average cost for one. If the saving by the reduction of grade was only half as much, or one train in eight, so that seven trains were required to do the work of eight on the steeper grade, then the saving per engine would be correspondingly less. If it were 2.5% instead of 5, we would have, for the cost of eight engines, 8×97.5, or 780 compared with 7×100, or 700 for the seven engines. Again, we would have 80% as the additional net cost of the repairs on the additional engine. Of course the above estimates of 5% and 2.5%, as the saving on one engine, are merely guesswork, but the above demonstration shows that if the saving in repairs is proportional to the reduction in number of trains which is made possible by the reduction of grade, as is quite probable, then the cost of the repairs of the extra engine is the same, whether it is one engine out of four, or one engine out of eight, or one engine out of any other number. Therefore, although the estimate of 5% per engine as made above is a guess, it is probably near enough to the truth, so that there is comparatively little error in using the figure of 80% for the additional cost of repairs of the additional engine.

The item of repairs of passenger-cars may or may not be affected, depending on whether the reduction of grade will actually affect the number of passenger-cars attached to a train. On trunk lines, when many of the most popular through express-trains must be operated in sections, because their length is actually limited by the rate of ruling grade, this item must be considered for its full value for as many trains as will be affected. But, on the large majority of the roads of the country, this item will be absolutely unaffected, and it will therefore be ignored in this calculation. Item 14, "repairs and renewals of freight-cars," will actually be reduced by the policy of reducing the number of cars hauled by one engine. Although the maximum draw-bar pull of the locomotive, and therefore its pull on the first car behind the engine, will be the same in either case, yet the *average* draw-bar pull for the lighter trains will be considerably less, and this will have its effect on the repairs of the draw-bar mechanism. A reduction in the weight of train will also have its effect on the cost of repairs, due to concussion and many other similar causes. The amount of this reduction is a matter almost of guesswork, as was also the reduction in the cost of the repairs of locomotives. Wellington claims that the cost of the repairs of the freight-cars involved would equal 10%, and we will therefore take that figure as a *negative* addition to the cost of operating the extra train. The other items of maintenance and equipment are evidently unaffected.

200. **Conducting transportation.**—Items 20, "cost of superintendence," will be practically unaffected. Item 21, "the wages of enginemen," will be given its full value. The additional cost for the fuel for the added engine may be computed somewhat on the same basis as the cost of engine repairs. The fuel used by four engines will average somewhat less than that used by three engines, since the four engines will do far less work on the level and on very light grades, while on the heavier grades the engines are working to the limit of their capacity in either case. The loss of heat, due to radiation and the other causes, which are independent of the direct work done by the engine in hauling, will be the same in either case. These causes have already been discussed in § 142. It is impossible to make any general calculations as to the relative consumption of fuel in the two cases, since so much depends on the proportion of track which is level or which has a very light grade. If the four engines operating lighter trains each burn 5% less fuel than three engines operating heavier trains, we will find, by the same method as before, that the extra engine may be charged with 80% of the average fuel consumption of the other three engines. If, as before, we assume that this variation in fuel consumption is proportional to the variation in the number of trains required to handle a given traffic, then the extra engine would be responsible for 80% of the average fuel

consumption, regardless of whether the number of trains saved was one in four or one in ten. Although it is true that the value 80% is a mere guess, that no general value is obtainable, and that the value for any particular and special case could only be computed with great difficulty, it is evident that the error is not very great, and we will therefore assume 80% as the fuel consumption assignable to the extra engine. The consumption of other engine-supplies, water, oil, waste, etc., is not strictly proportional to the consumption of fuel, but we will assume it to be so in this case, and that 80% of Items 23–25 are allowable for the extra engine.

Items 26 to 32, which concern train-service, will be considered as varying according to the number of train-miles, and we will therefore add 100% for all these items. The item of car-mileage is evidently unaffected. Items 33–37, which refer to damages, might be considered from one standpoint to be unaffected, while from other standpoints the effect might be considered as 100%. The risk of train operations varies very largely with the number of trains, and yet in some respects the danger is independent of whether there are 15 or 20 cars in a train. There will be little error in assigning 50% extra for this item. Items 38 to 44 are evidently unaffected. Items 45 and 46 will be considered as affected 50%. The general expenses are evidently unaffected. Collecting these various items we have Table XXIX. To this we will add, as before computed, an average charge of 0.25 c. per mile as the mileage charge for the capital cost of the extra engine.

If we assume that the average cost of a train-mile is $1.30, then the operating value per mile of saving the use of the additional engine equals 51.757% of $1.30, or 67.28 c. Adding 1.25 c. for the cost of the engine, we have 68.53 c., which we will call 69 c.

TABLE XXIX.—ADDITIONAL COST OF OPERATING A GIVEN FREIGHT TONNAGE WITH FOUR ENGINES ON HEAVY RULING GRADES INSTEAD OF WITH THREE ENGINES ON LIGHTER GRADES.

No.	Item (abbreviated).	Normal average, per cent	Per cent affected.	Cost per cent.
1	Roadway	10.767	12.5	1.346
2	Rails	1.422	50	.711
3	Ties	2.948	50	1.474
4	Bridges and culverts	2.461	0	0
5–10	Buildings, etc.	3.436	0	0
	Maintenance of way	21.034	.....	3.531
11	Superintendence	.617	0	0
12	Repairs of locomotives	6.538	80	5.230
13	" " passenger-cars	2.174	0	0
14	" " freight-cars	7.160	−10	−.716
15–19	Miscellaneous	1.535	0	0
	Maintenance of equipment	18.024	.....	4.514
20	Superintendence	1.757	0	0
21	Enginemen	9.607	100	9.607
22–25	Fuel, etc.	11.542	80	9.234
26–32	Train-service, etc.	23.149	100	23.149
33	Car-mileage	1.829	0	0
34–37	Damages, etc.	2.288	50	1.144
38–44	Miscellaneous	5.307	0	0
45–46	Stationery, etc.	1.157	50	.578
	Conducting transportation	56.636	.....	43.712
47–53	General expenses	4.305	0	0.
		100.000	....	51.757

201. Numerical illustration.—As a practical illustration of the above figures assume that the ruling grade on a given line is 1.4% (73.72 feet per mile). Assume that only 8 trains per day out of a total of 20 trains of all kinds are to be considered as affected by the rate of the ruling grade. Assume that it has been discovered that with the expenditure of $300,000 a change of alinement may be made which will reduce the ruling grade to 1%. Is such an expenditure justifiable under the circumstances? It has been shown in the chapter on Train Resistance that the actual tax on the locomotive depends quite largely on the ratio of live load to tare. Therefore the only comparison which can justifiably be made as the basis for planning construction is to assume the same conditions of loading for both cases. For this comparison we will assume the resistances taken from Mr. Dennis's paper, as already referred to in Chapter XI, §§ 128–133. The grade and tractive resistance for a rating ton on the 1.4% grade would be (28.0+2.6), or 30.6 pounds per ton. The tractive power, as given for Mr. Dennis's locomotive at the speed of 7 miles per hour, is 28,200 pounds. The gross rating tons which could be hauled at this speed therefore equals (28,200 ÷ 30.6), or 922 gross rating tons. The ratio of a tare ton to a rating ton on a 1.4% grade equals 121% (see § 129). The actual weight of the locomotive and tender was 130 tons. On the 1.4% grade the resistance of the locomotive would be that due to (121% × 130) = 157 rating tons. Subtracting this from 922, we have 765 rating tons behind the locomotive. On the basis that the live load is twice the tare, the actual weight of cars with their loading would equal

$$\frac{3}{2+1.21}\times 765 = 715 \text{ tons.}$$

Since $\frac{2}{3}$ of this weight consists of live load, the actual weight of live load carried in one train behind such an engine up the 1.4% grade is 477 tons. But, since we are assuming that these cars are loaded to the limit of their capacity, or at least to the same ratio of that limit, we will consider 715 tons as the total weight for both grades of the freight and of the cars which carry it. On a 1% grade the ratio of tare ton to rating ton is 128%. On this grade the locomotive has the equivalent weight of (128% × 130) = 166 rating tons. The eight trains, each of which are assumed to have a gross weight for cars and live load of 715 tons, will therefore weigh 5720 tons. On a 1% grade this will be the equivalent of

$$5720 \div \frac{3}{2+1.28} = 6254 \text{ rating tons.}$$

The grade and tractive resistance for a rating ton on a 1% grade equals (20.0+2.6), or 22.6 pounds per ton. This locomotive at seven miles per hour can therefore handle

$$28{,}200 \div 22.6 = 1248 \text{ rating tons.}$$

Subtracting 166 rating tons for the locomotive, we have left 1082 rating tons behind the tender as the capacity of one engine. Dividing 6254 by 1082, we have something less than 6, which shows that 6254 rating tons could be handled by six such engines with a margin of 238 rating tons. We may therefore say that, as the effect of reducing the ruling grade from 1.4% to 1%, the eight trains, which are affected by the rate of the ruling grade, can now be handled by six engines, and that there will be the saving due to the reduction of two trains. If these trains were operated 365 days per year, the annual saving on the basis of 69 c. per train-mile will be

$$2 \times \$0.69 \times 365 = \$503.70$$

per mile of length of that division. If the division is 100 miles long, the annual saving is $50,370. Capitalizing this at 5% we have an additional justifiable expenditure of $1,007,400. Since this is over three times the computed expenditure, which can be readily estimated as the cost of effecting this reduction in ruling grade, it would appear that the improvement is thoroughly justified, especially since future traffic will probably increase rather than diminish the value of the improvement.

CHAPTER XVI.

PUSHER GRADES.

202. General principles underlying the use of pusher-engines.—Whenever a road is laid out merely with the idea of passing through certain predetermined points and constructing the road as cheaply as possible, the usual result is that there will be a great variety of grades differing by small amounts from a level up to the actual maximum. In such cases it will usually happen that the term "ruling grade" will apply to only one or two grades along the entire length of the road. The length and weight of heavy trains will therefore be limited by these ruling grades, as already explained in the previous chapter. The obvious policy in such cases is to cut down these heaviest grades until some limit is reached, at which these heavy grades are so numerous and so long that any further reduction is financially, if not physically, impossible. The economics of such reduction of the ruling grade has already been considered in a previous chapter. It frequently happens that there are one or two grades along the line on which the tractive resistance is nearly, if not quite, twice the tractive resistance of any other grades on the line. In such cases the adoption of pusher grades becomes economical. If by using assistant engines to assist the heaviest trains over one or two steep grades, we are actually able to double the length or weight of our freight-trains, there is evidently an enormous saving, even though it requires the services of pusher-engines which are used for no other purpose.

203. Numerical illustration of the general principle.—In the following illustration the refinements regarding the hauling capacity of locomotives, as determined by rating tons, have been ignored. Assume that at one point on a road there is a grade of 1.9%, which is five miles long. Assume that all other grades are less than 0.92%. Assuming that all trains are to be operated by one engine throughout that division, the net capacity of a consolidation engine, weighing 107 tons, with 53 tons on the drivers, $\frac{9}{40}$ adhesion, and six pounds per ton for normal resistance, will be 435 tons on the 1.9% grade. This is therefore the maximum net train-load allowable with that type of engine. Assume that this 1.9% grade has a length of five miles, and that the whole division is 100 miles long. By using pusher-engines on this five-mile grade the net train-load can be doubled. These 870 tons can also be hauled by one engine up the 0.92% grades. Making a rough comparison, which is free from details and allowances, we may say

(*a*) Ten trains per day over a 100-mile division hauling 435 tons net per train will require 1000 engine-miles per day, which will haul 4350 net tons.

(*b*) Utilizing pusher-engines on the steep grade, the same tonnage of 4350 tons may be handled in five trains of 870 tons each behind the locomotive. The engine mileage will be 5×100 miles of the through-engines plus 2×5×5 pusher-engine miles, which makes a total of 550 engine-miles per day, instead of 1000, to handle a given traffic.

The advantages of this method are numerous. (1) There is not only a large saving in the number of engine-miles, but it may even mean a saving in the number of locomotives, since it may require the purchase and use of ten locomotives in place of seven. (2) The through-engines, which are hauling 870 tons along the easier grades, are working more nearly to the limit of their capacity for a large part of the distance, and therefore are doing their work more economically. The work of overcoming the normal track resistances of so many loaded cars over so many miles of track, and of elevating so many tons of train weight through the differences of elevation of the several points of the line, is approximately the same whatever the exact route. If the grades are so made that fewer engines, which are working more constantly to nearly the limit of their capacity, can accomplish the work as well as more engines, which are doing but little work for a considerable proportion of the time, the economy is very apparent and unquestionable. Wellington expresses it very concisely: "It is a truth of the first importance that the objection to high gradients is not the work which the engines have to do on them, but it is the work which they do *not* do when they thunder over the track with a light train behind them, from end to end of a division, in order that the needed power may be attained at a few scattered points where alone it is needed."

204. Equating through grades and pusher grades.—The above problem was purposely chosen with figures in which the pusher grade and the through grade were exactly balanced or equated. When it has once been decided that pusher grades should be used, then the problem of grade reduction is modified to the extent of concentrating effort and attention on the reduction of grades which may be less than the rate of the pusher grade, and to reduce them to the limit of the equated through grade. In other words, if it is decided to retain the 1.9% pusher grade, any intermediate grade between 1.9% and 0.92%, such as 1.4%, must necessarily be treated in one of four ways: (*a*) it must be reduced to 0.92%; (*b*) it might be operated as a pusher grade; (*c*) it might be operated as a through grade, which virtually means that all train-loads are reduced to the 1.4% basis; (*d*) a fourth *possible* method would be to use two pusher-engines on the steepest grade, as described below. Of course the first method is the proper method to adopt, if it can be done with a reasonable expenditure of money. The method of pusher grades is only applicable when it is possible to modify the system of grades on the road, so that there is an abrupt change from grades which are to be operated as pusher grades down to through grades which correspond with these pusher grades.

A somewhat unusual solution of a problem in pusher grades is given by the possibility of using two pusher-engines on some grades and one pusher-engine on correspondingly lower grades. Working out such a method on the basis of the engine previously considered, and assuming that the 1.9% grade is the grade for two pusher-engines, we might determine the corresponding grades for one pusher and for through engines as follows:

Tractive power of three engines $=106{,}000\times\frac{9}{40}\times3=$ 71,550 pounds.

Resistance on 1.9% grade $=6+(20\times1.9)=44$ lbs. per ton

$71{,}550\div44=1626=$ gross load in tons.

$1626-(3\times107)=1305=$ net load in tons.

$1305+(2\times107)=1519=$ gross load on the one-pusher grade.

Tractive power of two engines $=47{,}700$ lbs.

$47{,}700\div1519=31.40=$ possible tractive force in lbs. per ton.

$(31.40-6)\div20=1.27\%=$ permissible grade for one pusher.

$1305+107=1412=$ gross load on the through grade.

Tractive power of one engine $=23{,}850$ lbs.

$23{,}850\div1412=16.89=$ possible tractive force in lbs. per ton.

$(16.89-6)\div20=0.54\%=$ permissible through grade

On account of its simplicity the above problem has been worked out on the basis that the normal tractive resistance is uniformly six pounds per ton, and also that the normal adhesion of the drivers is $\frac{9}{40}$. On the basis of these figures the grades for one, two, and three engines are precisely as given above. Using other types of engines and assuming other values for the resistance and adhesion, the relation of these grades will change somewhat, although, as shown in the following tabular form, the variation will be but slight.

TABLE XXX.—RELATION OF ONE-PUSHER AND TWO-PUSHER GRADES TO THROUGH GRADES, WITH VARIATIONS OF THE RATIOS OF ADHESION AND NORMAL RESISTANCE.

Adhesion of drivers.	Resistance per ton.	Load on drivers.	Through grade.	One-pusher grade.	Two-pusher grade.
$\frac{1}{5}$	6 lbs.	53 tons.	.54%	1.26%	1.86%
$\frac{1}{5}$	7 "	53 "	.54	1.29	1.92
$\frac{9}{40}$	6 "	53 "	.54	1.27	1.90
$\frac{9}{40}$	7 "	53 "	.54	1.31	1.96
$\frac{1}{4}$	6 "	53 "	.54	1.28	1.93
$\frac{1}{4}$	7 "	53 "	.54	1.32	2.00

The above form shows that increasing the resistance per ton and decreasing the adhesion have opposite effects on altering the ratios of these grades, and, as a storm would increase the resistance and decrease the adhesion, the changes in the ratio would be compensated, although the absolute reduction in train-load might be considerable. Another practical inaccuracy in the above calculations is obtained from the fact that the rating tonnage on the pusher-engine service is different from that on the through-engine service. To determine the effect on the above case, let us consider the original problem of using a 1.9% grade as a pusher grade using one pusher-engine. Adopting the same figures as before of 2.6 pounds as the resistance of a rating ton and 9 pounds as the resistance of a ton of tare, we have, on the 1.9% grade, a gravity resistance of 38 pounds per ton, and therefore a total resistance of 40.6 pounds per ton for a rating ton. The resistance of a tare ton will be 47 pounds; therefore, to change tare tons into rating tons for a 1.9% grade, we multiply the tare ton by 116% (see Table XXI, § 129). Assuming, as before, an adhesion of $\frac{9}{40}$ of the 53 tons on the drivers, we have a tractive force of 23,850 pounds for one engine, or 47,700 for two engines. Dividing 47,700 by 40.6, we have 1175 rating tons for the whole train. The two engines weigh 214 tons, which is the equivalent of 248 rating tons. Subtracting this from 1175, we have 927 rating tons behind the two locomotives. Since the required through grade is still an unknown quantity, we must solve the problem by an assumption of the required through grade in order to determine the equivalent number of rating tons for one locomotive on the unknown grade. We know from the other solution that the through grade will probably be a little less than one per cent, but we know that it will probably be a little higher than the rate given by the other solution, since a locomotive has a higher resistance per ton than the average train resistance. The ratio of tare tons to rating tons on a one per cent grade is 128%, therefore the number of rating tons on the through grade must be very nearly $927+(107\times1.28)=1064$ rating tons. Dividing this into 23,850, the tractive power of one locomotive, we have 22.40 the total tractive resistance for one rating ton. Subtracting 2.6, we have 19.8, which is the grade resistance of a 0.99% grade. This value is somewhat higher than the 0.92% grade previously worked out, as was to have been expected. It should be noted, however, that even this value depends on the constants, 2.6 pounds for the resistance of a rating ton and 9 pounds for the resistance of a tare ton, as deduced from Dennis's experiments. If the solution is worked out on the basis of other values, the results will probably be somewhat different. On the other hand, it is somewhat encouraging that, in spite of the radical difference in the methods used, the difference in the final results are as small as given above. When separate methods give results which agree to a few hundredths of one per cent in the rate of the grade, we may consider that either are sufficiently accurate for practical use. In view of the variations in train resistance and the uncertainties of the relation between the resistance for a rating ton and the resistance of a tare ton, no table that can be devised will be accurate for all conditions. In Table XXXI is given the corresponding pusher grades for one- and two-pusher, for the same net load behind the locomotive for various through grades. These have been worked out for track resistance of six and eight pounds. The table is valuable in that it affords a very ready comparison of the relative rates of grade under the conditions named. On account of the extra resistance of the extra locomotive, the pusher grades are probably a few hundredths of one per cent too high, and a corresponding allowance should be made. As an illustration of the use of the table, let us answer the question of the permissible pusher grade when the through grade has already been estabished at 1.24%. If the road-bed is in good condition, we will assume the lower rate of track resistance or six pounds per ton. We will then interpolate between 2.34 and 2.50, and obtain 2.40% as the corresponding pusher grade. For the reason stated above, we should probably cut this down to about 2.3%.

As another illustration, if a road has a few grades of 1.8% which are not of excessive length and yet which cannot be materially reduced except at excessive cost, we may consider the question of operating these few grades as pusher grades, assuming that all through grades can be reduced to the corresponding through-grade limit. Assuming again a track resistance of six pounds and interpolating for 1.8% for one pusher, we have the corresponding through grade of 0.86%. For the same reason as before, this should probably be *increased* to at least 0.90% to obtain the correct balance. The question then is transformed into the possibility of reducing all grades which are not to be operated as pusher grades, so that none are above the limit of 0.90%. If the road under consideration is already in operation, a closer value may be obtained by considering the actual capabilities of the locomotives employed and the track resistance as it actually exists. For preliminary calculations the above figures are probably sufficiently accurate. It may be noted from Table XXXI that when the track resistance is increased from six to eight pounds per ton, the pusher grade corresponding to any through grade is increased. This is due to the fact that the net load which may be hauled on the through grade is considerably less, so much less than on the through grade that a larger part of the adhesion is available to overcome grade resistance.

205. Method of operation of pusher grades.—Much of the economy in the operation of pusher grades depends on the method of operation, which in turn depends on the method of their construction. When it is decided that pusher grades are necessary, the ideal method of construction is to concentrate the steep grades into one continuous rise. A turnout must be located very near the upper and lower ends of each pusher grade, so that the pusher-engine may be switched on and off the main track with a minimum of useless running. But the ideal arrangement of a continuous grade is not always practicable. It sometimes becomes necessary to lay out a pusher grade for a length of perhaps three or four miles, and then, after a mile or two of comparatively level track, another pusher grade several miles in length must be added. It will

TABLE XXXI.—BALANCED GRADES FOR ONE, TWO, AND THREE ENGINES.

Basis.—Through- and pusher-engines alike; consolidation type; total weight, 107 tons; weight on drivers, 53 tons; adhesion, $\frac{9}{40}$, giving a tractive force for each engine of 23,850 lbs.; normal track resistance, 6 and 8 lbs. per ton.

Through grade.	Track resistance, 6 lbs.			Track resistance, 8 lbs.		
	Net load for one engine in tons (2000 lbs.).	Corresponding pusher grade for *same net load.*		*Net* load for one engine in tons (2000 lbs.).	Corresponding pusher grade for *same net load.*	
		One pusher.	Two pushers.		One pusher.	Two pushers.
Level.	3868 tons	0.28%	0.55%	2874 tons	0.37%	0.72%
0.10%	2874 “	0.47	0.82	2278 “	0.56	0.98
0.20	2278 “	0.66	1.08	1880 “	0.74	1.23
0.30	1880 “	0.84	1.33	1596 “	0.92	1.47
0.40	1596 “	1.02	1.57	1384 “	1.09	1.70
0.50	1384 “	1.19	1.80	1218 “	1.27	1.92
0.60	1218 “	1.37	2.02	1085 “	1.44	2.14
0.70	1085 “	1.54	2.24	977 “	1.60	2.36
0.80	977 “	1.70	2.46	887 “	1.77	2.56
0.90	887 “	1.87	2.66	810 “	1.93	2.76
1.00	810 “	2.03	2.86	745 “	2.09	2.96
1.10	745 “	2.19	3.06	688 “	2.24	3.15
1.20	688 “	2.34	3.25	638 “	2.40	3.33
1.30	638 “	2.50	3.43	594 “	2.55	3.51
1.40	594 “	2.65	3.61	555 “	2.70	3.68
1.50	555 “	2.80	3.78	521 “	2.85	3.85
1.60	521 “	2.95	3.95	489 “	2.99	4.02
1.70	489 “	3.09	4.12	461 “	3.13	4.17
1.80	461 “	3.23	4.27	435 “	3.27	4.33
1.90	435 “	3.37	4.43	411 “	3.42	4.49
2.00	411 “	3.52	4.59	390 “	3.55	4.63
2.10	390 “	3.65	4.73	370 “	3.68	4.78
2.20	370 “	3.78	4.88	352 “	3.81	4.92
2.30	352 “	3.91	5.02	335 “	3.94	5.05
2.40	335 “	4.04	5.15	319 “	4.07	5.19
2.50	319 “	4.17	5.29	304 “	4.20	5.32

usually be more economical to operate the entire distance as a continuous pusher grade, in spite of the fact that for a mile or two the pusher-engine is utterly unnecessary. It would be very difficult to so arrange the schedule of trains that each section of such a pusher grade could be operated separately with separate engines and keep the engines continuously employed. Economy in pusher-engine service demands that each pusher-engine shall be working as nearly continuously as possible. On account of the great loss of economy that occurs when two sections of a pusher grade are separated by a mile or two of comparatively level track, the engineer can profitably expend considerable study and even surveying, by his corps of men, in the endeavor to so modify the line that the total required difference of elevation can be condensed into a single grade.

It has been demonstrated elsewhere that the loss of energy incurred in stopping a heavy train is sufficient to run it along a level track for a mile or more. It is therefore desirable to couple and uncouple the pusher-engine without stopping the train if it is possible. The pusher-engine takes its name from the frequent custom of using the assistant engine literally as a pusher behind a freight-train, which enables it to accomplish its work without stopping the freight-train either at the top or bottom of the grade. For passenger service the assistant engine is always coupled ahead of the through engine, which means practically that the train must be stopped when the assistant engine is coupled on. The stop at the top of the grade is avoided by merely uncoupling the locomotive while running, and then running it ahead at increased speed on to a flying-switch, where a switchman is located so that the passenger-train passes the switch without stopping.

When the traffic of a road is very heavy a pusher grade may have several pusher-engines, whose sole duty is to serve the trains on that grade. Under such conditions they can usually be operated economically. When the train service is comparatively light, the pusher-engines are not so steadily employed, and the cost of the pusher-engine service is proportionally higher for each train assisted. If the pusher grade is located very near or even within a few miles of a large freight-yard, at which switching-engines are constantly employed, a considerable economy is frequently possible by employing the pusher-engines alternately as switching-engines in the yard and as pusher-engines on the pusher grade.

A still further economy is possible on roads of very light traffic, where the use of a pusher-engine would be a luxury. On such roads the passenger-trains are usually very short and light, and therefore are probably not affected materially by the rate of the ruling grade. On such roads also a delay of even 50% in the time of hauling a freight-train over the road is of comparatively small importance. In such cases the road can still be designed on the basis of pusher grades. The freight-train can be loaded up to the capacity of a single engine on all through grades which are less than the pusher grade. The freight-train can then be cut in two at the bottom of the pusher grade, and one half of the train can be taken up separately. The total engine mileage is no greater than with pusher-engine service, and in fact may be somewhat less, for reasons given in the next section. Almost the only objection is that due to the loss in time, and on a road of very light traffic this is a small matter. This method should not be forgotten, particularly in the design of light-traffic roads, since it has all the advantages of enabling a road to be designed, if necessary, on a pusher-engine basis, and yet if the traffic should ever increase, so that the delay, due to this method of operation, becomes objectionable, the normal method of pusher-engine service may be adopted. The engineer should not forget that the pusher-engine method must not be discarded simply because the road may not at first have an amount of traffic which would justify the ordinary method of pusher-engine service.

206. Length of a pusher grade.—The actual mileage traveled by pusher-engines for each train assisted must be something in excess of *twice* the distance between the sidings at the top and bottom of the grade. Usually a telegraphic station at both the top and the bottom of the grade is at least very convenient if not essential to safe and efficient operation. If a regular stopping-place of the road is located even a mile or two *beyond* the top or bottom of the pusher grade, it will usually be found advisable, in spite of the added mileage, to have the pusher-engine service begin at the station. When the assistant engine is uncoupled from the train while running, the siding must evidently be at some little distance beyond the top of the grade, so as to give ample opportunity for the assistant engine to run onto a siding and have the switch turned before the train passes. All of these allowances add to the length of the pusher-engine service, which therefore makes it considerably more than the nominal length of the pusher-engine grade as taken from a profile of the road.

207. The cost of pusher-engine service.—When we analyze the elements of cost, we will find that many of them are dependent only on time, while others are dependent upon mileage. Still others are dependent on both. Very much will depend on the constancy of the service, and this in turn depends on the train schedule and on a variety of local conditions which must be considered for each particular case. The effect of a pusher-engine on maintenance of way may be considered to be the same as the cost of an additional engine to handle a given traffic, as developed in § 86. The same total allowance for the expenses of maintenance of way (3.53%) will therefore be made. Although the cost of repairs and renewals of engines is evidently a function of the mileage, and would therefore be somewhat less for a pusher-engine which did little work than for an engine which was worked to the limit of its capacity, yet it is only safe to make the same allowance as for other engines. Other items of maintenance of equipment are evidently to be ignored. The item of wages of enginemen will evidently depend upon the system employed on the particular road. Whatever the precise system the general result is to pay the enginemen as much in wages as the average payment for regular service, and therefore the full allowance for Item 21 will be made. Similarly we must allow the full cost of the items for engine-supplies. While the engine is doing its heavy work in climbing up the grade, the consumption of fuel and water is certainly greater than the average; but, on the other hand, on the return trip, when the engine is running light, it probably runs for a considerable portion of the distance actually without steam, and therefore the consumption of fuel and water will nearly, if not quite, average the consumption for an engine running up and down grade along the whole line. That portion of fuel consumption which is due to radiation, blowing-off steam, and the many other causes previously enumerated, will be the same regardless of the work done. We therefore allow 100% for all of these items of engine-supplies. In general we must add 100% for Items 28 and 29, the cost of switchmen and telegraphic service. While there might be cases where there would be no actual addition to the pay-rolls or the operating expenses on account of these items, we are not justified in general in neglecting to add the full quota for such service. Collecting these items we will have 37.20% of the average cost of a train-mile for the cost of each mile-run by the pusher-engine. Using the same figure as before, $1.30, for the cost of one train-mile, we have 48.36 c. for each mile-run. Again adding, as in § 200, 1.25 c. as interest charge on the cost of the pusher-engine, we have 49.61 c. for each mile.

TABLE XXXII.—COST FOR EACH MILE OF PUSHER-ENGINE SERVICE.

No.	Items (abbreviated).	Normal average.	Per cent affected.	Cost per engine-mile, per cent.
1	Repairs of roadway.	10.767	12.5	1.35
2	Renewals of rails.	1.422	50.	.71
3	" " ties.	2.948	50.	1.47
12	Repairs of locomotives.	6.538	100.	6.54
21	Enginemen.	9.607	100.	9.61
22–25	Engine-supplies.	11.542	100.	11.54
28	Switchmen, etc.	4.110	100.	4.11
29	Telegraph	1.875	100.	1.87
				37.20

208 Numerical illustrations of the cost of pusher service.—In § 204 we found that a through grade corresponding to a 1.9% pusher grade was 0.99%, or, in other words, that two engines of equal capacity could handle on a 1.9% grade a train which could be hauled by one engine on a 0.99% grade. Suppose that we have a road or division 100 miles long, which has a traffic of ten trains per day each way which must be assisted by pusher-engines. Two of the grades, 5 and 6.5 miles respectively, are against the traffic in one direction, and the other grade, with a length of 7.5 miles, is against the traffic in the other direction. There will therefore be a total of 19 miles of pusher-engine grade, on which ten trains per day must be assisted. Suppose that these maximum grades have been limited by suitable development to 1.9%. Suppose that the other grades are less than 1% or are so little above it that, with a comparatively small expenditure, they may be reduced to 1% or to 0.99%. How much money could justifiably be spent to accomplish the reduction of the other grades to keep them within the limit of

0.99%? There will be no object in cutting down these intermediate grades, unless by so doing we can double the train-load, even though doubling the train-load adds the expense of operating the pusher service. If the traffic of the road is sufficient for ten trains, such as could be hauled with one engine over the 0.99% grades, it will require twenty such trains to haul that traffic with one engine over 1.9% grades. Therefore, utilizing the pusher-engine service will save the operation of ten trains per day each way. If this particular division of the road is 100 miles long, the annual saving by cutting down the number of trains from twenty to ten, computed as in the previous chapter, will be

$$10 \times \$0.69 \times 100 \times 365 = \$241,850.$$

But this saving is accomplished only by the pusher service, which will cost

$$10 \times 19 \times 2 \times 49.61 \text{ c.} \times 365 = 68,809 \text{ per year.}$$

Capitalizing the net saving $173,041 at 5%, we have $3,460,820, which represents the amount which might justifiably be spent in reducing all grades except the three pusher grades down to the limit of 0.99%. The above estimate may need to be modified somewhat as to the cost of the pusher service. If these three pusher grades were so widely separated that each must be operated independently, then the pusher-engine mileage per day for the three grades would be 100, 130, and 150 miles respectively. Unless the schedules were favorably arranged for the pusher-engine service, it is quite possible that one engine might not be able to do the entire work on each of the grades. Freight-trains which require pusher-engine help usually move at a very low speed, probably less than 15 miles per hour, and at times not more than 10 miles per hour. One hundred and fifty miles per day for a pusher-engine implies a very well-arranged schedule, and therefore two pusher-engines might be needed instead of one. This would add considerably to the cost of the pusher-engine service. The cost of reducing these grades is a quantity which can be readily computed with all desired accuracy, therefore we can usually determine by an investigation like the above whether the plan of using a pusher-engine service is desirable, since the cost of reducing the grades might be very much less than the computed capitalization. In that case it would show that it would probably be justifiable to adopt such a policy and that any allowable inaccuracy in the method of estimating the difference in operating expenses would not alter the final result. On the other hand, if the cost of reducing the grades is materially greater than the capitalized value, the proper method is again clearly indicated. When the two values are substantially equal, it shows that there is but little choice, and that the choice must probably be determined by the facility with which the money for the improvement can be obtained. In applying the above methods to any particular case, the values given above should be closely studied and revised to agree as nearly as possible with the local conditions. The value of the cost of a pusher-engine mile given above is to be considered as merely illustrative of what the cost will be under some conditions. Under other conditions the variation will be considerable, and a value which will correspond with the local conditions should be determined.

CHAPTER XVII.

BALANCING GRADES FOR UNEQUAL TRAFFIC.

209. Nature of the subject.—In the preceding chapters it has been tacitly implied that the extent of the traffic in the two directions is equal, and that it is just as desirable to obtain a low grade in one direction as in the other. But it frequently happens that the freight traffic in one direction is far greater than the freight traffic in the opposite direction. Even on the main trunk lines running east and west, the east-bound ton-mileage has at times amounted to four or five times the west-bound ton-mileage. Between the years 1851 and 1885 the east-bound ton-mileage on the Pennsylvania Railroad averaged 3.7 times the west-bound ton-mileage. As an actual consequence, the west-bound freight-trains consisted very largely of "empties." As another corollary, a locomotive which could haul a certain number of loaded cars up a grade of 0.6%, which was against the east-bound traffic, could just as easily haul such cars as were loaded, together with the empties, which must be returned, up a considerably steeper grade, say 1.0%. Under such conditions there is little or no object (from the ruling-grade standpoint) of making the grade against the west-bound traffic any less than 1% when the east-bound traffic is as steep as 0.6%. The two grades, 0.6 and 1.0, have been selected offhand as two grades which *might* balance each other under certain conditions of relative traffic in the two directions. They illustrate the principle involved that the ruling grades in opposite directions should not necessarily be equal, but should probably be made unequal. It now remains to determine what should be the relation between the ruling grades in the two directions on any given road.

210. Illustrations in the balancing of grades.—This subject is one that chiefly concerns the great trunk lines of the country, which are constructed almost regardless of cost and at grades which are reduced to a low figure by a great expenditure of money. A very large number of railroads, especially branch lines which run from a main road up into the mountains, have one terminus much higher than the other, are laid out largely as "surface lines," and are therefore laid on such grades as can be obtained with a minimum of constructive work. On such a road the heavy grades may be almost entirely in one direction, which may or may not be against the heavy traffic.

Unless a road is of such importance that it can be largely rebuilt after its original construction, in order to correct the errors and deficiencies of the original work, we must consider the original location as a finality. It is frequently impossible to predict, with any great accuracy, what the traffic of the road will be, and especially that the traffic in one direction will be materially greater by any definite percentage than that in the other. The engineer is therefore seldom justified in attempting to make precise calculations of this sort previous to the construction of a new road.

211. Principles on which the theoretical balance must be computed.—A little thought will show the truth of the following statements. First, the number of locomotives and passenger-cars running in each direction is necessarily equal. Second, the number of passengers carried in opposite directions is practically equal. Even if we allow that there is a considerable immigrant traffic which increases slightly the load of passengers carried, it is useless to base any calculations on this, since the ratio of live load to dead load in passenger-cars is so very small that such a slight difference in the number of passengers carried in opposite directions as may exist can have absolutely no effect on the proper rate of grade. Third, empty cars have a greater resistance *per ton* than loaded cars; therefore, in computing the hauling capacity of a locomotive hauling so many tons of "empties," a larger figure must be used for the ordinary tractive resistances. This fact, so far as it goes, tends to equalize the differences in the two grades which might otherwise be computed. Fourth, owing to greater or less imperfections of management, a small percentage of cars will run empty or partly full in the direction of the greatest traffic. Fifth, freight having great bulk and weight (such as grain, lumber, coal, etc.) runs from the rural districts to the cities and manufacturing districts. Sixth, freight from manufacturing districts, although it pays comparatively high freight-rates and is actually more profitable to handle, weighs far less, and occupies less bulk. Seventh, changes in traffic conditions which are more or less permanent will alter the direction of the hauling of bulk freight. For instance, a farming district which is largely a dairying country frequently will not raise as much feed (hay and grain) as is needed to feed the cattle, and we have the apparent paradox of importing grain and feed into a farming country. Eighth, a change in the character of the country may permanently alter the ratio of the freight tonnage in the two directions. Such changes are already discernible in the traffic of the east and west lines and also in the north and south lines. The discovery of extensive coal-fields in the western part of the United States has largely changed the direction of the movement of this class of bulk freight. The exhaustion of supplies of timber in one section and the development of that industry in another has also had material influence in changing the relative flow of traffic. The development of the coal and iron industries in the South has largely changed the relative traffic flow in north and south lines.

212. Numerical illustration.—Assuming the same figures already considered in Chapter X, we will consider that the grade against the heaviest traffic and for fully loaded trains is 1%. The grade and tractive resistance for a rating ton on this grade is 22.6 pounds per ton. If the locomotive has a tractive power of 23,200 pounds, it can handle 1248 gross rating tons. The actual weight of the locomotive and tender is 130 tons; multiplying this by 128% for the 1% grade, we have 166 rating tons for the locomotive which leaves 1182 rating tons behind the tender. If the fully loaded trains have a live load equal to twice the weight of the cars, their actual tonnage will be $\frac{3}{2+1.28}\times 1182=1081$ tons. This means that the cars weigh 360 tons and the freight 721 tons. Assume that the total live load carried in the opposite direction is but $\frac{1}{3}$ of the above, we would then have 360 tons of cars and 240 tons of freight, which will aggregate 600 tons. To determine the rating tons corresponding to 600 actual tons of loading, we must make first a trial estimate of the grade in order to determine the value of a rating ton on that grade. We will assume as a trial that the grade is 1.6%. At this grade the ratio of a tare ton to a rating ton is 119%. Since the live load is $\frac{1}{3}$ of a nominal full load, which means that it is $\frac{2}{3}$ the weight of the cars, to reduce 600 actual tons to rating tons at 1.6% we must divide 600 by $\frac{\frac{2}{3}+1}{\frac{2}{3}+1.19}$, which equals 668 rating tons.

But on a 1.6% grade the 130-ton locomotive will have the equivalent weight of 155 rating tons. Adding this to 668 rating tons for the load behind the tender, we have 823 rating tons as the total weight of the train. If we divide the total tractive power 28,200 by 34.8, the tractive resistance of a rating ton on a 1.6% grade, we would have 811 as the total capacity in rating tons of the locomotive on the 1.6% grade. This agrees fairly well with 823, but it proves that the trial rate of grade, 1.6%, is a little too high. If we were to carry through another trial calculation on the basis of 1.5%, we would find a far greater discrepancy in the other direction. Considering that our assumption of the probable weight of the loading in the direction of light traffic is at its best a gross approximation, any over-refinement in these calculations is a mere waste of time. We may therefore say that, under the above conditions, a grade of 1% against the heaviest traffic will give as much resistance and require as much work of the engines as a grade of 1.6% against the assumed lighter traffic.

213. **Reliability of calculations of this nature.** — As before intimated, this is not a question which will ordinarily concern the engineer of a light-traffic, cross-country road. The practical difficulty of predicting the relative amount of traffic on a road before it is constructed, and the probability that such figures, no matter how correct they might be in the early history of the road, will be permanently altered in the course of 20 or 50 years, means that very little reliability can be placed on such computations except in a general way. The great east and west trunk lines, although they find that there are fluctuations in the relative amounts of traffic, have also discovered that, in a rough way, the east-bound traffic is permanently far greater than the west-bound traffic. The Pennsylvania Railroad, in the course of the carefully developed recon-

struction of their line and the building of a low-grade line between Philadelphia and Pittsburg, have kept this principle in mind, and have uniformly designed the ruling grade against the east-bound traffic at a considerably lower figure than that against the west-bound traffic. The Canadian Pacific has already begun extensive reconstruction of their line in order to follow this same principle. In an extreme case pusher grades may be used to accomplish the same object, but this does not alter the principle involved. A pusher grade should always be considered as a special case of a ruling grade of a little over one-half the rate which is operated in a special way, and the above principle is one which applies to the relative rate of the ruling grade. Although the engineer of a light-traffic road may not find it justifiable to spend any added amount of money to follow this principle, he should keep it in mind and endeavor to so design his ruling grades to conform to this principle, if it may be done with little, if any, added expenditure.

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