THE ECONOMIC LOCATION OF THE
LOCATION OF RAILWAYS.

R.R. Ghaemmaghami.

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SUBJECT OF THESIS:

THE
ECONOMIC THEORY
of the
LOCATION OF RAILWAYS

BY

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May 15, 1953

THE ECONOMIC THEORY
OF THE
LOCATION OF RAILWAYS

by

A. M. Wellington

Résumé by

F. R. Ghaemmaghami

Submitted to the Division of Engineering

as a Part of the Requirements in Transportation Seminar

Engineering 291-92

American University of Beirut

Beirut, Lebanon

15 May 1953

Dear reader,

I have finished my studies ten years ago in Roads and Constructions with M.A degree, and have 8years of experience in railroad constructions of Iran (my country) .

I began this thesis on January 6th , 1953 on the subject of Economic Theory of the Location of Railways

My first debt of gratitude is to Prof.C.Ken Weidner, Dean of the Division of Engineering of the American University of Beirut, Who has kindly furnished me with all the facilities and to him I am eternally grateful.

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F. R. Ghaemmaghami

Amir F.R.Ghaemmaghami

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THE ECONOMIC THEORY
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I. Railway construction at its simplest.

When we want to solve a general problem, we must understand the conditions as well as possible; when they are known we must make our survey and choose a way for constructing. It is clear that the way chosen must be as economic a way as possible, providing that nothing be done which will injure its permanent efficiency. "For example, a bridge must be strong enough to carry the load and last." But a little practice and a little study of geometry will enable any one of ordinary wisdom, to lay out a railway from almost anywhere to anywhere, which will allow trains to run with perfect safety and only in a few difficult localities will its location present a problem of great difficulty.

II. Railway construction by a trained engineer.

The true function and excuse for being of an engineer, as distinguished from a skilled laborer, begins and ends in comprehending a just balance between topographical possibilities, first cost, future revenue and operating expenses. In any case, our work must be without error. Errors which, even if committed, are not likely to be discovered, are really much to be feared, as a source of future danger.

III. Railway location engineering.

In laying out railway lines (as opposed to building) we must realize that the laws of topography, or even of finance, cannot be reduced to equations and formulae. Every line is a problem by itself, with its own peculiar physical and commercial conditions, so that the engineer is the one who must be able to give the details of the project. Under these circumstances, the difference of conditions will be apt to be accepted by one who may have sinned against good practice, as the reasons why another line, one hundred or one thousand miles off, should have cost so much less and yet be so much better than his own. Such an engineer must avoid complacency. The planning of railway location must be done by specially trained engineers. In the past, many railway lines have been planned by men who were really builders. The location engineer is now as necessary in building railways as an architect is necessary in erecting buildings. The railways of the world, in general, have cost twice as much as they need have in labor and money, because they were not planned by experts.

Possibility for waste.

The great world declines to take much interest in such greater waste in many things, and having something of that large indifference to waste which pervades all nature. Nor would it be worth while here to insist on it for the mere sake of pointing out that it exists, but solely to point out that, as the location of railways is the one department of engineering in which waste on a gigantic scale is possible from probable errors of judgment, and as it is likewise the one department of engineering in which no natural check exists against such errors, it is fitting that engineers should prepare themselves for it with especial care, at least to the extent of acquiring an adequate conception of the number and magnitude of the errors into which they may fall.

<u>Highest motives for economy</u>.

Much of the success of anyone in any kind of work and specially in work subject to the peculiar difficulties of that we are considering, depends upon the spirit in which it is undertaken. It is certainly true in a calling where the desire for personal gain or glory is not the motive. The desire to do good work for its own sake is then the only real guarantee that good work will be done.

As Emerson says "I look on that man as happy, who, when there is question of success, looks into his work for a reply - not into the market, not into opinion, not into patronage" and he says "Men talk as if victory were something fortunate. Work is victory. Wherever work is done, victory is obtained. There is no chance, and no blanks. You want but one verdict: if you have your own, you are secure of the rest."

PART I

ECONOMIC PROMISES.

PART I.

ECONOMIC PROMISES

CHAPTER I

The inspection of railway projects,and conditions governing it.

For constructing railways in a part of a country two considerations are very important:

First, designing the project, second, financing it.

The railway systems of the world, taken as a whole, and especially that of the United States, have been only very moderately profitable in any direct form; owing not so much to mistakes of judgment pure and simple, as to the very large proportion of lines which have been built simply to increase the value of land and to afford local transportation facilities, with a resulting gain to the community.

Often railways are not profitable for governments, but for the above reasons we have to construct them. However the expenditure must be minimum, and we must spend no more than we are obliged to spend to build the line. Therefore, we must be able at first to control the enterprise as well as possible.

The logical order of procedure in the case of any new enterprise - which is, first, to determine whether or not the project is a sound one and may be carried out; and, secondly, to make the necessary studies as to the manner of carrying it out - is not always followed in this order. The study may come first. A study of a plan for a railway assumes that the project is a sound one and that it can be carried out efficiently and economically.

No expenditure is wise, however otherwise profitable, which endangers the successful completion of the enterprise with the funds on hand or known to be available; but expenditures of any kind on new projects are rarely wise and profitable, which can be postponed without any very serious loss, such as costly works which can be avoided by temporary lines.

Determining if a line will be profitable.

The profit on a railway property depends, first, on the judgment shown in selecting the region through which it is to be built; and, secondly, on the skill with which the line laid down in it is adapted to be of the greatest use to the greatest number of people (giving large gross revenue) at the smallest cost for the service rendered (giving small operating expenses). The first is distinctively the province of the projectors; the last is distinctively the province of the engineer. The engineer must lay out his work after the above considerations considering only the effects of his decisions upon these three items:

1) The difference in gross receipts which will or may result from choosing one or another line,

2) The difference in operating expenses which will or may result from choosing one or another line, one or another gradient, one or another limit of curvature, etc.,

3) The difference in annual interest charge which will or may result from the differences in cost of construction caused by differences in the above details. Unless specific reasons to the contrary appear, the cheapest line is to be built over which it is physically possible to carry the probable traffic with proper safety and speed, using to this end any grades and curves and length of line which may be most conducive to this end only - and never abandoning it by increasing the expenditure,

unless the investment - not the investment as a whole, for the line as a whole but each particular investment for each particular purpose at each particular point - will be in one way or another profitable in itself.

The most important or the governing consideration is simply an avoidance of waste, either in saving money or in spending it.

Errors to be avoided.

These two vital truths should never be forgotten:

1) because a line is expected to have a prosperous future or is to be built by the State for great reasons of state (strategic or political) - or for any other reason, will have plenty of money in the treasury - there is therefore no justification in that fact alone for making a costly road. In difficult country when one must spend large sums per mile one must be specially on one's guard to avoid spending more than absolutely necessary.

2) no road is so poor that it can afford to economize when certain additional expenditure will be clearly very profitable. In easy country one must avoid the adoption of unduly high gradients to effect a really trifling economy in mileage.

Preliminary consideration.

The selection of general route, termini, or, as very often happens, the selection of one or both termini as well.

The question of general route is commonly settled by the Reconnaissance, which for this reason is the most important duty of the engineer in charge, and the one for which it is most essential that he should qualify. The reconnoitering engineer must be trained in both engineering and economics, lest he give undue weight to purely engineering questions as against pecuniary advantages.

CHAPTER II

The modern Railway Corporation

Modern railway corporations, even the strongest of them, have but a narrow margin for mistakes. It is absolutely necessary to have that fact before the eyes, in order that the atmosphere of wealth which surrounds the period of construction may not lead us to foolish expenditures. The hope in building a railway is that when it is completed, it will be worth more than it has cost, so that a profit will accrue. Actually in most countries, owing to increased population and rising costs, the railways that have been built have risen in value far above their initial cost and tend to be very productive.

The most important thing for modern railway corporations is their economic aspects and therefore we have to give attention, first to the economic possibilities. It has frequently happened that enterprises have appeared to be of so sound a character that they have been almost immediately able to borrow on mortgage their entire capital for construction, or even a still larger sum and the original projectors and true "owners" of the property have not been required to invest anything whatever in the property themselves beyond their original sagacity in initiating the enterprise - a quality which has its value in railway business, as in most other human affairs. The speculative interest in modern times is supposed to be represented by the stocks or shares in the company or by railway bonds. In a country where the future is all uncertain, but where population and traffic are advancing, lines are built, not for the traffic which exists, but for the traffic which is to come even. This may take a speculative character, and may involve as much hazard as large investors can be persuaded to consent to. So it was with the organization of United States railways.

Railways will continue to be built in other parts of the world as these are opened to modern industry on bonds and also with faith and hope, but with the margin of financial safety taken up by state financing.

As the real value of a railway property increases, and if business of railway is profitable then begins the process of "watering", i.e. increasing the stock or bonds by new issues until their total amount bears a nearer relation to the present value or productive capacity of the property, as distinguished from its original cost.

Even in a state-owned and operated railway though its value shows an "unearned increment", the management must see that its monopoly powers shall not be used oppressively, to charge more than a fair equivalent for service, as measured by practice elsewhere or on other kinds of traffic, under similar circumstances; but the just increase in value of a well-located railway, which does not abuse its monopoly powers to make unjust exactions, is fairly the property of the owners, however large, unless and until the public are prepared to insure the investors a certain minimum return as well as deny them uncertain excess profits. It may be added, that the mortgage or bonding process is carried on to a greater extent in railway than other business simply because, unlike most other business enterprises, a certain considerable fraction but only a fraction, of the income of their property is in the nature of monopoly which no conceivable circumstances can destroy.

CHAPTER III

The Nature and Causes Connected with Location which Modify the Volume of Railway Revenue.

With the invention of the railway began a new industry - the Manufacture of Transportation. Transportation indeed, existed before its invention but it was mainly produced on a small scale by each consumer for his own use and his immediate neighbors. In the Middle East this chiefly took the form of the Caravan, later motor transportation to a limited extent.

A Railway corporation such as has been just considered - the typical modern corporation - exists for this purpose. It finds itself, on completion of its works, in possession of a certain piece of improved real estate, of certain buildings and fixed machinery (the track), and of certain tools and machines (the rolling-stock) for the manufacture of its commodities, together with certain establishments (the locomotive and car shops) for the maintenance and repair of its machine-tools, which the extent of its business requires.

Making a line short, though it may reduce the initial cost, may also reduce the revenue in two ways 1) by missing certain towns whose traffic might bring in a good revenue and 2) by reducing the amount of revenue calculated on mileage - also, leaving aside strategic arguments, rail connections between smaller cities and the capital further the development of the country economically and commercially. "Manufacture" of transportation differs from the manufacture of actual goods in that what is not sold (passenger seats or capacity in freight cars) on one day or on one trip cannot be stored for later sale. Therefore, to put revenue higher than operating costs and fixed charges, no effort must be spared to see that the maximum amount is sold each time.

The suggestion is put forward in respect to every part and kind of railway traffic that it is on slight differences of traffic and revenue that the corporation grows rich or poor.

Factors affecting Traffic and Revenue.

1) The length of the line. All rates except by special contract are nominally fixed by unit of distance.

2) The comparative weight allowed to securing way traffic from smaller cities (way traffic).

3) How near to run to cities, towns, and other sources of traffic, which are already upon the line, and how much the traffic and revenue will be thereby affected.

4) Branch lines: whether to build a branch at all, or take the main line through the given point; whether, if a branch be decided on, the connection should be made at this or that point, there being often much choice, and the decision governed by commercial considerations to an unusual extent, or at least by laws very different from those which might govern the laying out of longer lines, owing to the shortness and isolation of most branches.

5) Connection of isolated lines into a single great system of railway.

In a certain sense, in a certain small part of its traffic, as already noted, there is a certain fraction of the traffic of all railways which no folly can destroy or throw away. But in a larger sense, the traffic of any and all railways is only to a very limited extent a monopoly of such nature that to secure it the Company has nothing more to do than to put up its buildings and man the stations. The selling of transportation is governed to a very large extent, whether there be nominal competition or not by the same laws which govern the selling of any other commodity; and these laws require that the railway company like any one else with something to sell, shall consult the convenience, and even sometimes the unreasonable whims, of the buyer, if it would sell its goods to him. For only a small proportion of the traffic must come to it anyhow, under all circumstances. Nevertheless no railway is so prosperous and so favorably situated that it would not, in literal truth, starve to death on the minimum logical traffic. The traffic would be so very greatly decreased that on most lines it would not be possible to run the trains at all. Neglecting altogether the traffic of which a very large proportion of the business of the railway system as a whole is made up, as respects passenger business, not only of pleasure travel pure and simple, but of travel which is more or less a matter of whim or of fancied or partial necessity; and even as respects freight business, of freight which will not be shipped except under reasonably favorable circumstances, or shipped only at a lower rate, we must not assume that: "If the railway does not go to the traffic, the traffic will come to the railway". This is a dangerous and false argument. Even when a railway can, or thinks it can, count on permanent immunity from competition, it should naturally follow from what has preceded that it is still exceedingly dangerous to put the public to permanent inconvenience and expense under the false idea that "it will cost the Company nothing". Even building a railway two or three kilometres from a town in an effort to shorten the line will result in slightly lower revenue. This five per cent difference may make all the difference between running this section of the line at a profit or at a loss.

There is one peculiar phase of the question of Running by a Town to save distance which may be more appropriately considered in this connection, as illustrating what has preceded, than in the chapter on distance.

Let us suppose, to take definite figures, that we have run by a town of ten thousand inhabitants in order to save a deviation of five miles from an air line, involving a loss of a mile or two of distance. As we have already seen previously, and shall more fully see later, the railway's revenue account suffers heavy loss due to the decreased mileage on most of its local and through business, competitive and non-competitive.

Thus under any possible conditions, in such a case there is a triple loss: the tax on the public is greater, the receipts of the railway are less per passenger or ton, and the number of passengers or tons is decreased.

The net losses might be estimated something in this way, assuming the town, say, to be in Ohio:

Table I.

Estimated Effect on Revenue of Removing Stations from the Centre of Population of Towns

Distance Miles	Minimum 10 per cent per mile		Ordinary Maximum 25 per cent per mile		Extreme Maximum
	Difference Per cent.	Per cent.	Difference Per cent.	Per cent.	
0	.....	100.0	.....	100.0	Very materially greater under certain circumstances, especially with sharp competition, so that a difference of two or three miles often means the loss of nearly the whole traffic.
1	10.0	90.0	25.0	75.0	
2	9.0	81.0	18.75	56.25	
3........	8.1	72.9	14.06	42.2	
4	7.3	65.6	10.55	31.65	
5	6.6	59.0	7.91	23.74	
6........	5.9	53.1	5.94	17.80	
7	5.3	47.8	4.45	13.35	
8	4.8	43.0	3.34	10.01	
9	4.3	38.7	2.50	7.50	
10.......	3.8	34.9	1.87	5.62	
Av. revenue per head per year	$ 2.00 to $ 3.00		$ 8.00 to $15.00		

Column 1. - Average distance of station from centre of population.

Columns 2 and 4. - Loss per cent of total natural revenue for each additional mile of distance.

Columns 3 and 4. - Remaining per cent of natural revenue left to the company.

Making all allowances for possible errors in the precise figures used in Table I, it represents an immense loss to all parties from running railways by towns without going to them, so far as the traffic of that town above is concerned, separately considered. There is, however, this further disadvantage to be remembered: if we lengthen the line to reach a town we necessitate that the whole traffic shall be hauled over this extra distance in order to accommodate the traffic of one town. As the actual cost of such trifling extra haul is very little, the net effect of such deviation for such a purpose is very apt to have a favorable effect, upon the net revenue derived from the entire traffic, independent of that from the particular point for the sake of which the deviation was made, as well as upon the public interest.

Importance of the Engineer.

Remembering also that errors in the original laying out of the line, unlike errors in subsequent management, are mainly irremediable, - it will be seen how large is the interest of the company who employ and pay the engineer in avoiding all errors of the kind, and how particularly important it is that no possible difference should be regarded as trifling because it will constitute a trifling part of the total receipts or expenses. It is always true that a heavy percentage of the surplus or deficit which alone concerns the company proper is strictly dependent upon the engineer and upon those, by whatever name they may be called, who decide with him, or for him, the semi-engineering and semi-commercial questions which we have here considered.

Therefore, with an end so important before us, any guide is better than none, in order that we may reduce the unavoidable uncertainty to its lowest terms; and under these circumstances a rule which Wellington has formulated as a sort of general average to estimate exceptions from, is this:

As a minimum: At the smallest and most inert non-competitive points the annual loss of revenue from placing the station at a distance from town may be taken as equivalent to 10 per cent of revenue naturally originating from such a town, with the station in any given location, for each additional mile that the station is moved off from the centre of the town.

As a maximum: At centres of considerable manufacturing or commercial activity, exposed to considerable actual or potential competition, a fair and moderate estimate of the probable loss of revenue from removing the station at a distance will be 25 per cent of the revenue naturally originating at such a town, for each additional mile that the station is moved off fr om the centre of the town; and this is frequently liable, in cases of very sharp competition, to amount to as much as 50 per cent of the natural revenue, including all the indirect effects of such disadvantages.

The first of these estimates, Wellington has considered to be applicable to such towns as the average of interior Mexico. The last is a fair average (varying however within wide extremes) of all the busier towns and cities of the United States.

The causes of variations are:

1) Manufacturing and specially mining towns are usually heavy shippers.

2) Towns which are the seats of special industries often make payments to railways out of all proportion to their apprent size and activity.

3) The number of competing lines will greatly affect the proportion tributary to any one line.

The effect of this rule is presented numerically in Table I - the percentages being in geometrical ratio to each other, so that any number in the column, divided by the first or second or third number above it, gives always the same quotient. Of course it should never be forgotten that: The towns will in many cases move to the railway, if the railway does not come to the town, with ultimate benefit to all parties concerned, this is especially common in Iran, but it is more or less true everywhere.

However, in the case of very large cities in Europe and America it has usually proved necessary to build railway lines, surface or underground into the centre of population to take care of suburban population. Though no such development as this has taken place yet nor seems likely in the immediate future in Iran, yet it is possible that one day it may be necessary to have a station in the heart of Teheran at least for passenger traffic.

In very large cities like New York, Philadelphia, Chicago, the distinctly suburban traffic, making daily trips at commutation rates, is a large element, which especially requires the best attainable terminal facilities and the largest possible saving of time.

At almost all points in the United States the probabilities of future growth must be remembered, which will sometimes, as at New York, bring a point which is, for the time being, considerably outside of the centres of population into the very heart of it.

It should never be forgotten: it is unsafe for any engineer to enter upon the work of laying out a railway with no more thought of its financial future than a vague idea that the passenger revenue is obtained by selling tickets, and the freight revenue is measured by the sum of the way-bills, and that neither is any concern of his; his duty being simply to get the shortest, cheapest, and straightest line, - the phrase has almost hardened into a formula, - and that when he has got it he has done his whole duty.

CHAPTER IV

The probable volume of Traffic, and law of Growth Therein.

To determine the probable volume of traffic with exactness is of course impossible; nor is it, fortunately, particularly important to do so, if we make a reasonably close approximation; for the reason elsewhere discussed, that, with a judiciously located line, the saving by adopting a poorer line than one naturally adapted to the topography is ordinarily not so great that any probable deficiency in the estimate of traffic would permit of it; while, on the other hand, the cost of defying the natural topographical conditions is ordinarily too great for any probable excess in the estimate of traffic to permit of it wrongly. In other words, the danger lies in having no criterion, or in a false perspective as to the relative importance of various ends, or in purely arbitrary decisions based on no investigation whatever, rather than in a certain percentage of error in our criterion.

In a rude way it can be done at once by any one at all familiar with railroad work. We know at once whether a line is more likely to have a light local traffic or a trunk-line traffic. It is but a step further to determine with very approximate exactness that a line will have somewhat more traffic than this or that or the other line near it, or similarly situated in other regions, and less traffic than as many others; from which the establishment of a mean for the immediate traffic and its future growth is with some knowledge of railroad business a simple matter.

The greatest difficulty in making such estimates is ordinarily the fact that to make them it is essential to estimate and allow for the probable future growth of traffic, since it is rarely the case that a railway, especially in the United States, is built simply and only to accommodate the traffic "in sight", as miners say. On the contrary, it has been and will continue to be frequently the case that the railway is relied upon not only to accommodate but to create a great part or the whole of the traffic for which it is built. Even when the population of the region traversed cannot, as it can in most parts of the United States, be expected to rapidly increase, experience has shown that if the surrounding territory has heretofore been but scantily provided with railway facilities, the traffic of the first few years will be but a small proportion of what would normally be expected from a similar population elsewhere, and that it may be expected for the first few years to have an abnormally rapid growth.

In all but the rarest instances, it would be absurd to claim that no allowance should be made for future growth of traffic, and often it should be a very large one. It is sufficient to build for the estimated traffic of the next ten years.

Table II

Growth of English Railways and Railway Traffic.

Year.	Miles			Capital		No. of Passengers. Millions
	Double or more	Single	Total	Total 1 = $1,000,000.	Per Mile. 1=$1000	
1855	6,153	2,182	8,335	1446.	173.4	118.6
1860	6,690	3,743	10,433	1692.	164.0	163.4
1865	7,711	6,143	13,854	2213.	166.6	251.9
1870	8,338	7,038	15,376	2574.	165.7	336.5
1875	8,898	7,760	16,658	3061.	183.8	507.0
1880	9,803	8,130	17,933	3537.	197.2	603.9
1884	10,239	8,625	18,864	3892.	206.1	695.0

Table II (Cont'd)

Year	Receipts					Per Cent Operating Expenses.	Per Cent. Net Receipts to Capital
	Total Millions	Per Mile of Road	Per Train Mile	Per Cent from - Pass.	Per Cent from - Freight		
	$	$	cts.				
1855	104.6	12,530	140.6	49.7	50.3	....	....
1860	134.8	12,930	131.5	47.1	50.9	47	4.19
1865	174.4	13,120	125.0	46.2	53.8	48	4.11
1870	210.8	13,570	124.4	42.8	53.5	48	4.41
1875	286.3	17,200	136.5	42.0	54.3	54	4.45
1880	306.0	17,040	127.2	41.5	54.6	51	4.38
1884	328.8	17,440	121.3	42.6	53.4	53	4.16

If, for example, we expect the traffic to double in ten years, we may spend for a betterment worth $1 to the present traffic, $1 + the sum which will produce $1 at the end of ten years, which latter is at 7 per cent 50.8 cents; so under these conditions we should be warranted in spending 50.8% more money to effect given betterments than we would for the traffic "in-sight".

Yet the rate of growth of traffic is excessively variable and uncertain - liable to cease altogether at any time for many years, and during periods of war or of political and economic crisis, for example during the present oil crisis in Iran, traffic may alter in a way impossible to have been predicted a few years before.

It is at such times especially to be remembered that the curve of traffic may drop sharply at any time, and that even if it does not, one must have good reason to build a line in anticipation of much heavier traffic.

A sequence of events which has been again and again repeated is that the company shall enter upon the work with vague visions of boundless prosperity, and look with certainty to securing "all the money they need"; shall encourage their engineer in a costly style of construction which, with the natural preference of an engineer for massive, durable, and stately works, he is all too ready to adopt; and finally, often within a ridiculously short time of the period of their brightest hopes, be left stranded by the ebb-tide of speculation, a complete and helpless financial wreck.

More Economical to Leave Expansion till Later

Finally, there is another and still stronger reason why the growth of traffic should not be counted on for many years ahead in designing the works. It is usually a simple matter so to design large parts of the line, including most of the more expensive works, that their construction may be postponed until a more convenient season - a possibility so important that it is separately discussed hereafter. By so doing we at least make sure of keeping the capital account at a minimum and of (usually) retaining the line in the hands of the original company; while, when all causes are considered, the loss from postponing the execution of all more costly work which can be postponed will not be very great, even if one's brightest dreams are realized - which will rarely be the case.

We may conclude, therefore, that although a railway corporation which has in truth as well as in imagination unlimited means; which is able to look ahead with certainty for a long period of years, which is able without doubt to tide over long periods of depression without danger to its stability, and which has no anxiety to realize present profit, or even avoid present losses, on investments which will be ultimately profitable; - although such a corporation may legitimately make a large increase in its investments for the sake of a traffic which is still in the distant future, yet that no ordinary corporation can afford to look ahead more than two to five years for the traffic to pay interests on increased investments, and that even in that case they take much risk in doing so. Traffic should therefore, in all cases, be rather under- than over-estimated, to the end that in no case extravagant expenditures shall be made for a costly perfection of alignment which the traffic will not justify; bearing in mind that an under-estimate of admissible expenditure is simply a failure to invest a small (or it may be, large) additional sum of money which would have earned good interest, but which may be invested later at nearly if not quite as good advantage; whereas an over-liberal investment of additional sums on which interest cannot be earned greatly endangers, in the trying years which usually come soon after the line is opened, the permanency of the whole investment.

In the one case, our economy only endangers a minor loss, if the enterprise as a whole turns out well; and if it does not, may save it from ruin. In the other case, our extravagance only gives us a fair investment for a little more money if all goes well, and if it does not, may be the ounce of additional load which breaks the back of the enterprise. Our only grave danger, therefore, is of error in one direction only; which makes it the easier to make an estimate of traffic sufficiently exact for all important purposes - that is to say, one which will be certainly not too large.

The most accurate and satisfactory method for estimating both traffic and expenses in any given case, however, is comparison with the experience of neighboring roads of the same general character, because it is much easier to count on a line doing so much better or worse than another line, than to estimate the absolute traffic independently.

Experience has shown that the probable number of trains per day is at once the most convenient and the most exact basis for arriving at estimates of probable future traffic, and especially expenses. It is the most convenient, because it can be more easily and more correctly anticipated than any other item of future business, - as tonnage, for example, - and also because we use the same unit for all our traffic, both freight and passenger; and it is the most exact, because it is by very much the most uniform, measure of operating expenses, the cost of a train-mile being very nearly the same whether the trains are run full or empty, or long or short, and not being materially different for freight or passenger service, although usually less, by one third to one fourth, for the latter, as we shall see hereafter.

Assuming, therefore, this basis for estimates, it may be always anticipated that there will be one passenger train per day each way, and that, unless the traffic be exceedingly limited, this train will be exclusively for passengers. Mixed trains, so called, are in but little and decreasing favor with railway managers, although it is not always possible to avoid them. When used at all, they are usually nothing more than freight trains under another name - accommodations for a few passengers being added chiefly as a convenience to special classes of travel, in the hope that such additional convenience may have, as it usually does, a favorable influence on the volume of travel. With freight traffic of course no such motives intervene to modify the number of trains, so that mixed trains are always freight trains carrying a few passengers, and never, in regular service, passenger trains carrying freight.

Therefore, under the most unfavorable circumstances there are pretty sure to be two regular trains per day, one passenger and one freight or "mixed" train, over lines of any length. Less than this is certainly never contemplated on lines built as private business enterprises, unless on very short branches built as feeders.

The point at which it becomes reasonable to anticipate running two regular passenger trains daily is more difficult to determine for different countries are different. It is impossible, in fact, until the volume of travel becomes large and the number of passenger trains at least two or three per day, to make any attempt to regulat the number of trains so as to have them run full, without serious injury to net revenue.

Beyond three or four trains per day there is much less necessity, as a rule, to add trains to accommodate and develop travel until the seating capacity itself becomes too small; this being one of the many cases in which "the destruction of the poor is their poverty". Nevertheless the results of experience with even the heaviest traffic is that it does not pay to economize too much on train facilities. Certain trains carry enormous loads and bring up the average materially, but a multitude of trains carrying much lighter loads are run with the heaviest traffic, at frequent intervals, bringing about the close correspondence in average train-load on roads of widely different character.

It is not expedient, nor indeed possible, therefore, to base estimates of the probable number of passenger trains on estimates or statistics of the probable number of passengers to be carried, further than to assume that the smaller the traffic the smaller will be the average number of passengers per train.

The same is true, in less degree, even of estimates of the probable number of freight trains. It is not correct to assume a certain tonnage to be moved, divide that by the load of a car to get the number of loaded cars, divide that again by the number of cars per train, and so get the number of trains. There is always, in the first place, a certain wastage of capacity amounting to anywhere from ten to thirty per cent according to circumstances, which, if the traffic is to be estimated on the basis of tonnage, must be allowed for. This wastage also, as with passenger business, is a much less serious matter on lines of large traffic, especially those with a heavy excess of tonnage in one direction; for in this case, although the average car-load in both directions is much reduced, yet in the direction of heaviest traffic the obtaining of full loads is facilitated. A very heavy disproportion of traffic, from three or four to one, exists on nearly all east and west lines in the United States; and most of them succeed in filling up their average car-load and train-load, in the direction of the heaviest traffic, to very nearly its nominal capacity. Nevertheless, even on such lines, fluctuations and irregularities of traffic are always so great, that it is no infrequent spectacle to see trains running light in the direction of heaviest traffic; and the difficulty of fully filling up trains, of course, becomes much greater as the tonnage is less, or, as already stated, when it is nearly equal in each direction. There is also always one train per day, the way-freight, which averages little more than one half an ordinary train-load, owing to the irregular service.

Nevertheless, it still remains true that in the main, excepting the "way-freight", the freight traffic can be and is regulated in close accordance with the volume which offers from day to day. So many freight trains, usually from two to six, are put upon the time table. If more are needed, "extras" - a train running behind another train and "on its time", but with a certain number of minutes interval - are added, each succeeding "extra" except the last, carrying a red "flag" as a signal that another train having its time-table "rights" is following.

On the other hand, if less trains are needed than appear on the schedule, such and such trains are abandoned for the day - often for days and weeks together, even when other trains are running extras. A near approach to conditions which actually obtain in practice will be given by assuming that the number of daily freight trains will always be one more than is nominally required by the tonnage, and more often the office of the extra trains being simply to serve as equalizers.

CHAPTER V

Operating Expenses

The average operating expenses for the whole United States is a little under 90% of the receipts, leaving but little more than 10% profit on the goods sold to be distributed to the managing companies. Under favorable circumstances this profit is as much as 15 or 20 per cent; very rarely more.

Beyond the operating expenses this 10% must be nearly all, all, or more than all, distributed in fixed charges that is interest on borrowed moneys (bonds) and dividends on shares. The ratio of expenses to receipts may be a smaller ratio when there is little or no competition, as in state-owned railways.

The operating expenses proper are very irregularly affected by the amount of business or by the character of the alignment. A very large proportion of them are, like the rental or fixed charges, independent of both, such as the salary of the president and other officers; maintenance of works and plant against the deterioration which comes with time, irrespective of work done; salaries of local freight and passenger agents, a large proportion of whom must be employed anyway, whether considerable sales are made or not. This immense class of the expenses amounts, as we shall see, to nearly one half of the operating expenses proper - the other half only varying more or less closely with the details of the line and grades, and very much less than half with slight changes in volume of traffic.

An increase in revenue by increasing traffic represents almost a pure increase in profit. Therefore, if traffic can be increased by a different aligment, the engineer's work in this respect is very important.

The operating expenses of railways divide, naturally, for the purpose which we have immediately in view, and in the main for all purposes, into the three great classes below.

1) Maintenance and Renewal of Way and Works, including all permanent structures and buildings, except engine and car-shops.

This has until recently averaged very uniformly 25 per cent of the total expenses on all American railways. It is now decreasing both relatively and absolutely, but far less rapidly than might be expected, because of both temporary and permanent causes below mentioned.

2) Train Expenses, including all expenses of every nature and kind connected with the running, handling, maintenance and renewal of motive-power and rolling-stock, but not including any station or terminal expenses, except switching. These expenses have heretofore averaged very close to 42 per cent of the total operating expenses.

3) Station, Terminal, and General Expenses and Taxes. With these we are very little concerned. Most of them vary more or less (for the most part,less) with the tonnage or volume of business; but all of them are independent of, or appreciably affected by, any of the details of lines and grades, and therefore, for our present purpose, may be included together and neglected, except as to their aggregate. Taxes at first sight appear to be affected by the alignment, in so far as they might increase with the length of the road; but taxes are based upon value and not on cost, and hence, although nominally based upon distance, are in reality much more truly based upon low grades, large traffic, and good rates. They are, moreover, too small and variable an item to justify their consideration as one of the expenses affected by any of the details of alignment. Station expenses also, and all the other expenses mentioned, are the same for the same business, whatever changes in the alignment may be made, except as such change brings additional way business; but even then the change will rarely

be sufficient appreciably to modify the station expenses.

Cost of Fuel

The cost of fuel per gross ton on American railways in 1880 ranged from a minimum of $1.20 to $1.50 on roads obtaining coal at mines on their own road, to a maximum of $4.00 to $5.00 at the least favored points east of the Missouri River, and in some cases to $6.00 or more at points west of there.

The consumption of fuel was as an average about 45 to 50 lbs. per mile run for heavy passenger trains. A passenger engine running light, without any train, burns nearly as much as this, or from 20 to 30 lbs. per mile. A heavily loaded freight engine of the "American" eight-wheel type will burn almost 75 lbs. per mile, a heavy "Mogul" about 90 lbs. per mile, and a "Consolidation" engine from 100 to 120 lbs. Several newly invented types of compound locomotive engines, having separate high-pressure and low-pressure cylinders were extensively introduced in Europe with, it was said, very satisfactory results.

The consumption of fuel on English railways in general, however, was lower than prevailed in the United States, although very much less so than commonly supposed. The proportion of switching is very heavy on English railways, the ratio of engine-miles to train-miles being almost uniformly as high as 125 to 100, and in some cases, as high as 177 to 100.

On German railways the average consumption was about 50 lbs. per revenue mile, costing about six cents.

The cost of fuel per mile run can be calculated from the above data for any particular line. In absolute cost, it is by far the most variable element in the running expenses of railways, but its percentage to the other expenses is considerable less variable, owing to the fact that the same causes which make fuel more expensive,also increase the other expenses to a considerable extent.

Repairs of Engines

The fall in the cost of this item, of late years, has been very rapid, but it is probably now at about its minimum, unless and until some new process of manufacturing steel and iron shall materially reduce the cost of the raw material, especially in shapes. For this purpose solid steel castings in lieu of forgings seem to be already on the verge of coming into general use. From 5 to 8 cents may be considered as about average at that time for all classes of engines, on roads with sufficient traffic to have proper facilities for economy in shop work. Wages do not vary widely in any part of the United States, and no cases exist for very wide fluctuations in this item.

Repairs of course vary materially with the class of engine and it would be quite impossible to give exact statistical evidence on this point which could be regarded as satisfactory. It may be estimated, however, with a very considerable degree of certainty, as follows:

About one-eighth of the cost of engine repairs is for repairs of tenders, which is of course substantially the same for any class of engine. The remaining cost is almost equally divided between material and labor. The cost of the labor is but very slightly affected by the weight of the engine and its various parts, although in accordance with the weight, but not fully so, many of the more expensive parts being substantially the same in all engines. If, therefore, we say that half the total cost of engine repairs (including the tender) varies with the weight, and half is independent thereof, it will probably be very nearly exact, for engines engaged in the same service, and equally well adapted mechanically for that service.

Cost of Water

Water-supply cost about half a cent per train-mile as an average, sometimes running below that on roads of very heavy traffic, but oftener running nearer to one cent per mile. On all but roads of very considerable traffic one cent was the safer estimate. The quantity used was very considerable. Practically the consumption of water, as of coal, was irregular, and a full tank might in cases be used up within fifteen miles; requiring, for practical convenience, tanks every ten miles, which is the average on roads of thin or average traffic. On lines of heavy traffic, tanks are placed at average intervals of hardly more than five or six miles.

Cost of Repairs

Repairs of cars can be estimated with most correctness per car-mile, (in 1880) and not per train-mile. For example, the figures may be roughly placed, with a very fair degree of correctness, at 1/5 cent per freight car-mile and 1 1/2 cents per passenger car-mile, on the larger roads. On small roads 1/2 cent per car-mile for freight-car repairs is more nearly correct. However, as in the case of engine repairs, this includes only labor and material directly applied to the cars themselves, and there is a considerable amount of incidental expenditure, which is really a part of the actual cost of maintaining the cars, but which is yet, for very proper reasons already stated, not generally included in the reported cost of car repairs. Such general and incidental expenses amount to from 10 to 25 per cent of the total cost of car repairs proper.

The established mileage rate for interchange of traffic is 3/4 cent per car-mile, this rate having been attained by a gradual drop from 3 cents to 2 cents, to 1 1/2 cent, to 1 cent, and at last to the present rate, 3/4 cent, and including (or being intended to include) a certain profit on the use of the cars sufficient to take away all inducement for keeping foreign cars in home service, if not to place a certain penalty on such use. It is probable that, as an average of several years, the price stated is sufficient to do this, especially as in addition to this sum the road using foreign cars is required to make good, at its own expense, any deterioration which parts of the car other than the wheels and axles may suffer while on its lines. Nevertheless, whenever business is brisk and cars are scarce, which may be one half to two thirds of the time, the price fixed is not sufficient to cause cars to be sent home, and earnest efforts are now making to bring about a change.

The apparent cost of car repairs, to an even greater extent than the cost of engine repairs, has been and will continue to be far smaller than it really is because of the constant additions of new stock, made necessary by the rapid growth of traffic. As the repairs on new cars are small for many years, if the stock of cars be doubling every four or five years, as has been the case in the United States for the past twenty years, the apparent cost of repairs cannot but be greatly affected.

We are less concerned, however, as in the case of engine repairs, with the total cost of car repairs than with its origin and subdivisions; as in that way only can we properly determine what effect differences of grade and line, or other specific causes, will have upon the cost of this item. Few railways keep, and none publish, any detailed record of the cost of the various items which make up the enormous aggregate of "repairs of cars", that being the only one which appears in the reports, or, as a rule, on the books. It is therefore difficult to determine precisely the ratio of the various items to each other. Nevertheless, from the information given in Table III we may conclude that the actual cost of repairs and renewals of freight cars is divided very nearly as follows:-

Wheels	30	per cent
Axles, brasses, and axle-boxes	30	"
Springs	10	"
Truck frame and fittings	5	"
Total truck	75	"
Brakes	5	"
Draw-bars	10	"
Sills and attachments	5	"
Car body, painting, etc.	5	"
Total	100	"

Table III

	Labor	Material	Total	Scrap Value	Total Deprec'n.	Average Life Years.	Annual Deprec'n
Wheels							
Axles							
Brasses							
Frame							
Truck							
Brakes							
Draw-bars							
Frame							
Roof							
Floor							
Sides							
Painting							
Trimmings							
Trusses							
Total,							

Passenger-car repairs are, for wheels, axles, and brasses, all slightly more than for a freight car per mile. Exact information as to the comparative mileage of passenger and freight wheels is difficult to obtain, owing to the fact that as soon as wheels show any noticeable defect, which yet does not make them unsafe, they are withdrawn from passenger service and put under freight cars, often making a large mileage before being finally scrapped. The general tendency of the available evidence is that there is but little difference, and that difference in favor of passenger cars, the effect of the higher speed being counterbalanced by less injurious brakes and better springs. The extra cost of repairs and renewals of passenger cars is mainly in its decorations, better painting, and interior fittings; and bearing in mind that passenger cars are not exposed to anything like the rough service, blows, and shocks which come upon freight cars, we may say, without any error of moment, that the average cost per passenger car-mile is about as follows:

	Frt.car. Cts. Per Mile.	Pass. car. Cts. Per Mile.
Running gear, draw-bars etc.	0.3	0.5
Sills, frames, etc.	0.1	0.2
Painting and varnishing car body	---	0.2
Interior fittings and upholstery	---	0.5
Total	0.4	1.4

In other words, the cost of maintaining a passenger car for those items or parts of items which are affected by difference of distance, curvature, and gradients is not so much greater than for freight cars, but that it is noticeably smaller per passenger train-mile, but the TOTAL cost of repairs per train-mile is about the same.

Train Wages, the sole remaining considerable item affected by line and grades, are less difficult than the preceding to state with correctness. The following are a close approximation to the rates which now prevail in America for average runs of a hundred miles. In 1870-74 they were naturally higher than this, say 25 per cent, and higher yet in the preceding decade. In 1875-78 they were about 10 per cent lower. They vary considerably in different parts of the country, but less than any other item of train expenses:

	Freight	Passenger
Engineman	\$3.50 to \$3.75	\$3.50 to \$4.00
Firemen	1.75 to 2.00	1.75 to 2.00
Conductor	2.75 to 3.00	3.75 to 5.00
Brakeman (each \$1.75)	3.50 to 5.25	3.50 to 3.50
Baggage-men	.. ..	2.00 to 3.00
	\$11.50 to 14.00	\$14.50 to 16.50

General and Station Expenses are but slightly affected by any probable variations in the line and grades, so that it is unnecessary to consider them in detail, although, for many questions connected with the operations of railways, such analysis is highly important. They amount altogether to about thirty per cent of the total operating expenses, ranging from twenty to forty per cent in extreme cases.

CHAPTER VI

The Minor Details of Aligment

The nature and relative importance of the minor details of aligment.

The three details of aligment which are properly to be classed as minor details are the following:

1) Distance, or length of line

2) Curvature, not sharp or so ill-placed as to limit the length or necessary speed of trains, but only to increase the expense of running trains,

3) Rise and Fall, or elevations overcome by the engine on gradients not exceeding in resistance the maximum of the road, and hence not limiting the length of the train,

We have two other details of overwhelming importance, viz:

1) The amount of traffic which the line has been or may be adapted to secure,

2) The ruling gradients or other causes, whatever they may be, which limit the weight and length of train, and so play the chief part in fixing the cost of handling the traffic.

We may further enforce the very important moral of the comparative unimportance of the minor details of aligment by what is really a close parallel from ordinary business life.

Let us assume the case of a large wholesale house which sends out its traveling salesmen to all parts of the country to obtain business. Every time it sends one out it has a reasonable certainty of selling something and a possibility of selling a good deal. Such a house may be compared to a railway corporation, which sends out its trains to secure a certain minimum but varying maximum of traffic.

Now in the conduct of such a business there are three ends:

1) To sell all the goods possible,
2) To dispense with all the miles of travel possible,
3) To reduce the cost of travel per mile,

So in planning a railway there are these three ends, precisely analogous to the former in their nature, and as nearly as may be in degree:

1) To sell all the transportation possible,
2) To dispense with all the train-miles possible,
3) To reduce the cost of running trains per mile.

Of all the three ends sought in the drumming business, the least important - the minor detail of the drumming business, is to reduce the direct cost of travelling; the expenditures for railway and sleeping-car fares and to hotels. Not that they are unimportant, for the firm which was reckless about them might readily be ruined; but they are a minor detail, of small effect upon the ultimate result, whether they be large or small, if the business as a whole be well planned and well conducted; and the firm which should concentrate its attention upon them, giving its thought to selecting routes where the travelling expenses per day or per mile were small, to the neglect of the more important question of securing more business or reducing the amount of travel required, whether it cost per mile or per day were large or small, would be justly deemed on the road to ruin.

No doubt many have been so ruined, for the petty end which the dullest mind cannot fail to perceive and comprehend may fill, from that fact, an unduly large arc in the mental horizon of many.

And, finally, the second most important end in the drumming business is to obtain the most business with the least possible aggregate of travel, because avoidable travelling is expensive, not only from its direct cost, but from its waste of the salesman's time and possible earnings in more productive localities. If in any possible way one salesman can be made to do the work of two, or two salesman the work of three, the economy is so great that any probable or possible difference in the salesman's expenses per mile will hardly affect the question at all. So with a railway corporation; the second most important end is to do their business with the least number of trains per mile, because making one train do what two did before saves all the expense of the extra train, whereas cutting out some curvature or distance will only save a part of it - and a very small part. Until all has been done which can be done, therefore, to reduce the number of trains required, it is hardly worth while to give a thought to reducing the expenses per train-mile. Afterwards it becomes proper and important to reduce the latter also, to the extent that is permissible without encroaching on the two more important ends; to get the business to carry and to make a few trains carry it.

The student can do no more profitable thing to qualify himself for the correct conduct of location than to ponder over the parallel thus drawn until it is clearly perceived to be essentially true, not only in substance but in degree; until he clearly perceives that the three ends of getting business, of saving needless travel, and of reducing the direct mileage expenditures should occupy about an equal proportion of the attention of an engineer building a railway and a salesman building up trade. Each is important. No one of them can be safely neglected; but each in the order given is far more important than the other.

Why this is so in railway business appears more in detail in the three following chapters.

CHAPTER VII

Distance

The effect of a variation in the length of a railway on the value of the property we have seen (Chap.III) to be peculiar in this - that, alone among all the details of alignment, it has a direct and material effect, not only on expenses but on the revenue or receipts, which tends very materially to reduce its financial disadvantage.

The origin lies in a seris of plausible fallacies, which are, in a few words, these - no one of them being true.

1) Rates are (usually and whenever possible) fixed at so much per mile, because (fallacy I) it costs so much per mile to transport the passenger or freight. Ten per cent more or less distance means ten per cent more or less fare, and "necessarily" (fallacy 2) ten per cent more or less expense.

2) But on our particular railway the service rendered is just as valuable, if transportation be furnished from the point desired to the point desired, whether the intermediate distance be 90 miles or 100 miles, and hence we shall "of course" (fallacy 3) receive the same money for it.

3) All extra distance adds greatly to the cost of the service (fallacy I,2) adds nothing to the value of the service (true enough with certain limitations), hence adds nothing to revenue (fallacy 3) and hence is among the greatest of disadvantages.

It has happened that the distance transported has been made the basis for traffic (when they have any basis whatever other than the amount which it is possible to c-ollect), as measuring in a rude way, not the cost of service, but consumer's idea of its value. Grades, curvature, cost of construction, terminal expenses, volume of traffic, whether the cars return full or empty - all these have very much more to do with the cost of service than the mere distance transported, but they are entirely neglected in fixing schedules of rates, simply because the consumer is not conscious of receiving any value when he is transported over curvature or grades, but is conscious of receiving value when he is transported over distance.

The effect of distance on operating expenses

The cost of operating additional distance not only is not the same per mile as the average cost but it is not even a constant quantity per unit of additional length; that is to say, is by no means the same per mile when the addition to be considered is one mile as when it is twenty. With the small changes of distance which most frequently occur, the number of yearly trips of rolling-stock, the number of buildings and sidings, and the considerable class of expenditures which vary therewith, remain practically constant, as well as (very frequently), train wages, and are not perceptibly affected until the change of length amounts to a considerable percentage.

Maintenance of way.- The entire cost of maintenance of way proper (excluding yards and structures) may, without any serious exaggeration, be considered as varying with changes of distance as great as 2 or 3 miles.

Fuel. - A very considerable percentage of the consumption of fuel is a constant wastage independent of the exact distance run.

Repairs of Engines and Cars. - It is exceedingly common, and for certain purposes proper enough, to assume these expenses to vary directly with distance, but for our present purpose this is very erroneous.

General expenses and Taxes. - Taxes are nominally assumed at so much per mile, and no doubt really vary with mileage to some extent, in fact as well as in form. As they are in the long-run,however, based on value and not on cost, it can hardly be proper to consider them as varying with distance to any important extent, and unless a longer line between two given points increases the value of the property, they should not increase with distance at all.

The effect of distance on receipts.

All railway traffic is in general roughly divided into "through" and "local", but what is through and what is local is a matter of varying definition. The literal interpretation of the word "through" freight passing over the entire distance between termini, whether exhhanged with other lines or not, and this definition is often followed in classifying. Another basis for subdividing traffic into through and local is that adopted in the Massachusetts Railroad Reports; viz. to call all traffic "local" which is confined to the home road and simply passes from one stationof the road to another, whether those stations are the termini or not; and all traffic "through" which is not local, but passes over parts of two or more lines, although the total haul may be only a few miles between small non-competitive stations; where as "local" traffic may be hauled the entire length of the road at competitive rates, and befor all practical purposes, what is ordinarily understood as "through" business.

Neither basis of division, therefore, is a particularly happy one for accomplishing the end sought, and the reason why neither can be is easy to see. The difficulty is that each of them is an attempt to include under only two classifications five distinct classes of traffic, each one governed by different laws as respects rates and other business considerations. These classes are:

A 1) Non-competitive local
  2) Non-competitive exchange

B 3) Competitive local
4) Competitive exchange

C 5) Partially competitive (i.e. Competitive only with the disadvantage of a local haul in addition)

More in detail, the nature of these sub-classifications is as follows:

A Non-competitive	1. Local or home traffic proper, having no choice of route and confined to one line 2. Exchange traffic or (by Massachusetts classification) "through" traffic, having no choice of route, but passing from one line to another.
B Competitive	3. Local or home traffic, confined to one line, but having a choice of another route (a class of traffic once small, but rapidly increasing with the multiplication of railways) 4. Exchange or "through" traffic proper passing between the more important railway centres, and with a choice of two or more routes.
C Partially competitive	5. Traffic (usually exchange or "through" between non-competitive local points and important railway centres having a choice of route only at disadvantage, by paying a local rate in addition to the "through". This class does not exist, practically, for passenger service.

Non-competitive (class 1 and 2). Traffic between non-competitive way points, whether these points are on the same or different roads.

There is no real need for making a distinction between these two classes in respect to rates, the "through" being made simply by the addition of the two local rates, and divided in the same proportion.

This class of traffic, which is what is popularly meant by "way" traffic, is an immense factor in the freight revenue of any railway, varying ordinarily from 50 to 75 per cent of it; and rarely falling below 50 per cent, except on lines of heavy through traffic running through sparsely settled district.

Competitive traffic, whether confined to one line or not; (classes 3, 4 and 5 above). The total through rates on all competitive traffic are, in nearly all cases, arbitrarily fixed, with little regard to the mileage. For this reason it may appear, and may be too readily taken for granted, by engineers not familiar with operating practices, that for this class of traffic at least, any additional distance must be a pure disadvantage, increasing expense, but not affecting revenue. And this is literally true with respect to such competitive traffic as begins and ends on one line, or on one system of lines with interests wholly in common. But, in spite of the present tendency to consolidation, a very large proportion of such traffic on all lines, and practically the whole of it on the smaller lines, is through freight proper, which passes over parts of several lines. On all such traffic the total rate from shipping point to destination is indeed arbitrarily fixed, without regard to mileage, and often in fact in inverse ratio to it; but of the division of this total rate between the participating companies, which is what practically concerns us, this is by no means the case.

Certain considerable allowances for terminal charges at points where such charges are heavy are very commonly and very justly deducted from the through rate before the latter is distributed, as notably in New York, where the terminal allowances are very heavy (4 to 5 cents per 100 lbs) although hardly enough to cover the direct and indirect expense to the terminal road.

In fact the variations and exceptions in the fixing and division of rates are endless, but through them all the general law holds good that all "through" rates betweeh connecting lines are divided precisely according to the actual mileage, and to a very large extent directly as the mileage.

These facts result in a curious and apparently contradictory law, as respects the through traffic of a new or old road, which it may be highly important that the engineer should understand. That law may be thus expressed:

1. It is extremely desirable that any new line should form a part of the shortest routes between important centres of traffic.

2. It is not desirable, and often the reverse of desirable, that it should make any effort to bring about this result, except in selecting its connections.

The reason for each half of this law is not difficult to see.

All way traffic, however, is not by any means rates solely by the mile; nor would any railway think of attempting so to rate it, even if it had the power to do so, without destroying business.

For the remainder of the traffic, to which the greater rate for the extra distance would be a real hardship and burden, it is entirely at the discretion of a railway company to do away with the extra burden by special rates based on volume of business furnished; and this is the true and just principle of fixing rates under all circumstances; for the interest both of the stockholders and the general public.

Especially when the question comes up of Lengthening the line to secure Way Business, as suggested in Chapter III we may almost say that where there seems any room for doubt it will almost always be good policy to do so. Extra business to a railway - the engineer will rarely err in thinking -

is almost all clear profit. Of passenger business this is literally true until the increase becomes considerable.

Let us suppose, for example, that A. & B. Railway 100 miles long, is deflected 10 miles north to strike some way point C. The increase of length, if the road were all a straight line, would be as nearly as may be two miles, and the extra cost of running those two miles probably fifty to seventy-five cents per train, as already estimated.

FIG.I.

The doubting engineer may safely take the two following as prima-facie guides, to be deviated from only as special reason to the contrary appears:

1) Any deviation which will increase the average per mile of road of tributary population (weighing the latter, of course, in proportion to their revenue-producing capacity) is all but certainly expedient, because it is mathematically demonstrable that the longer line ought then to be for the joint advantage of the community and the railway.

2) Even if the gain be considerably less than this, the deviation may easily be (and probably is) for the interest of the railway, ahtough not in that case expedient in itself, as a question of public policy .

All the preceding conclusions as to the comparatively slight importance of distance (and the same is true of all the minor details of alignment) may well lead to ruinous consequences if they are stretched until they crack to support some extended and radical change materially modifying the cost and convenience of transportations, and so discouraging traffic; for it must never be lost sight of, although it's disadvantages may be more than made up to one party by the gains; the danger of permanent disaster to the property is great.

The point which it has been sought to bring out is, that even in extreme cases there always is a credit side of considerable importance to increase of distance - contrary to the idea which prevails to an unfortunate extent, that a short and direct line is the first desideratum, to which almost everything else must bend.

There is another argument, of much the same vague kind as that last referred to, but of a more reasonable and tangible character, which is sometimes brought up as a reason for saving distance, viz. the "Moral Effect" of a short line in helping to secure traffic. Nor is this argument wholly unjustified, for there are numerous lines throughout the country which do apparently suffer simply from the length of their line frightening away passengers and fast-freight traffic.

Many lines which are not particularly direct, however, do not do this, and the prosperity of a single conspicuous line, the New York Central & Hudson River Railroad, will show that there is nothing in distance pure and simple to deter travel until, as in the case of the Grand Trunk Railway in competing for American business, the difference of distance becomes so great as seriously to lengthen the Total Time of the trip - a result not commonly to be feared from probably engineering modifications of any given time.

The difficulty is (par.51) that the lines least favored as to distance are generally less desirable in other respects. There are more connections to make, less favorable through-car arrangements, a less number of and slower trains, etc. etc. At the very worst, moreover, this objection only applies to a very small portion, and that the least profitable portion, of the traffic of a road; and it does not apply at all to those small changes, of a few miles more or less, which the engineer is most frequently called upon to consider, and to which this chapter has mainly referred.

CHAPTER VIII

Curvature

It is the peculiarity of curvature that all its disadvantages lie upon the surface, visible to every eye and comprehensible by every mind. A visible defect or danger is always more keenly appreciated and dreaded than one which it requires special training to detect; it is evident that this simple fact must always have a powerful if undetected influence while human nature remains what it is.

And when we come to consider what are the more solid objections to curvature, we find at once that a formidable and undeniably true list of objections to it may be made, consisting of many counts; as thus:

1) It causes a considerable loss of power and considerably more wear and tear on rolling-stock and road-bed, thus increasing expenses,

2) It does or may limit the length of trains, and thus still more increase expenses,

3) It causes a considerable expense for extra watchfulness and track-walking, and thus indirectly still more increases expenses,

These three are what may be called the definite and positive objections to curvature. But there are still others which are essentially indeterminate:

4) The danger of derailment is increased, and the consequences of such derailment when it occurs are more likely to be serious,

5) The danger of collision is increased by the obstruction of the view,

6) There is more difficulty in making time, and thus passenger travel is likely to be affected.

7) It injuriously affects the smooth riding of cars, and thus deters travel,

8) It impresses the imagination of travellers with a feeling of danger even if none exists, and thus in a third way affects travel unfavorably; and, finally,

9) It is more or less an obstacle to the use of the heaviest and most powerful types of engines.

It is therefore not unnatural that a very general course of reasoning on the question should be: "Each one of these objections to curvature amounts to something; plainly, therefore, in the aggregate they must amount to a great deal, although no one can ever determine exactly how much. If the curvature be sharp they will be several times more serious, and in fact will then become entirely inadmissible for such a line as ours." Thence may follow, perhaps too quickly, a conclusion in the form of an order to the engineers who are to examine the country, to the effect that "the minimum radius of curvature permitted on this line will be," etc. - an order from which thereafter there will be no retreat.

The Danger of Accident from Curvature

Railway accidents come from a great variety of causes, of which curvature is one. How great a cause it may be is made difficult to determine by the fact that accidents are rarely reported as directly chargeable to curvature, its effect being rather to aggravate them or to prevent timely discovery that there is danger of accidents from other causes, than to cause them itself.

The general character of the line is irrevocably fixed by the topographical conditions. The engineer is not called upon to decide between the crooked solid line and the straight dotted line in Fig.2, but between a little more and a little less curvature as indicated by the solid and nearly parallel dotted lines.

FIG.2.

If we could eliminate all curvature from railways we have to decrease by 25 or 50 per cent the danger to life and property.

Unfortunately, from the very fact that curvature plays so small a part as a cause of accident, no general statistics can be given as to the number of cases in which it does have an influence.

The truth is that nothing but a standing miracle keeps either curvature or any other cause of accident from being a fruitful source of disaster. The marvellous safety of railway travel in the face of such numberless chances for disaster is one of the most impressive triumphs of human care and skill, and it is this fact alone which gives our argument any force whatever. No one could have foreseen it, and hardly any one can fully realize it; but the fact being as it is, true wisdom requires that we should recognize its consequences, and not insist on trusting to the imagination for arguments in a purely practical question.

Among English engineers curves are usually defined as of so many chains (66 ft.) radius. The radius of a 1° curve in chains is $\frac{5729.65}{66}$ = 86,813 chains, so that the one method of designation may be converted into the other by the formulae

$$R \text{ in Chains} = \frac{86.813}{D}, \quad \text{and } D = \frac{86.813}{R \text{ in Chains}}$$

Continental engineers designate curves by the radius in metres. The radius in metres of a 1° curve being $\frac{5729.65}{3.2804}$ = 1746.4 metres, we have, for converting the one method of designation into the other, the similar formulae,

$$R \text{ in metres} = \frac{1746.4}{D}, \quad \text{and } D = \frac{1746.4}{R \text{ in metres}}$$

American engineers, and those adopting American practice, when working with the metric system, use, as the unit chord, a chain of 20 metres (65.61 ft) divided into 100 links of 2 decimetres (.656 ft) each. The radius of a curve having 1° of central angle for a chord of 100 of any unit is 5730 (5729.65) of that unit, so that the radius in metres of a 1° metric curve is 5729.65 x 0.2 = 1145.93 (1146) metres, or one fifth as many metres as there are feet in the radius of a 1° foot curve - as is natural from the fact that there are only one fifth as many units in the chord.

In stationing under the metric system, however, the best practice is to use 10-metre stations, setting stakes at every other station only (or 1 chain apart) on tangents and easy curves, and at every station (or half-chain) on sharp curves. In practice this produces little inconvenience.

Whether with English or metric measures, on sharper curves than 8° or 10°, the chord becomes so much shorter than the subtended arc that it becomes inaccurate to assume the radius as $\frac{5730}{D}$. To obviate this difficulty, it is now becoming usual in the best practice to run in curves sharper than 8° with half the usual unit chord, or 50 ft., and to run in curves sharper than 16° with <u>one fourth</u> usual unit chord. It then becomes literally true, to the nearest even foot, that the radius of all curves, of watever degree, is given by the formula: $R = \frac{5730}{D}$.

Table IV gives the radii in feet, chains, and metres of all the curves below 30° which are much used for either metric or English measures. We now resume consideration of the various objections to curvature.

<u>TABLE IV</u> (<u>Over</u>)

TABLE IV

Radii of Curves of Various Degrees in Feet, Chains, and Metres

Degree of Curve		Curves run by English Measures			Curves Run by Metric Measures (20 M. Chain)	
		Radius in Feet	Radius in Chains	Radius in Metres	Radius in Metres	Radius in Feet
0° 30'		11,460	173.626	3,492.8	2,291.86	7,519.2
0° 50'		6,876	100.408	2,095.7	1,375.12	4,511.5
1°	Unit	5,730	86.813	1,746.4	1,145.93	3,759.6
1° 40'	Chord	3,438	52.089	1,047.8	687.56	2,255.8
2°	- 100	2,865	43.406	873.2	572.96	1,879.8
2° 30'		2,292	34.726	698.6	458.28	1,503.8
3°		1,910	28,938	582.1	381.98	1,253.2
3° 20'		1,719	26.044	523.9	343.78	1,127.9
4°		1,433	21.704	436.6	286.48	939.9
5°		1,146	17.363	349.3	229.19	751.9
6°		955	14.469	291.1	190.99	626.6
7°		819	12.402	278.1	163.70	537.1
8°		717	10.852	218.3	143.24	470.0
9°		637	9.646	194.0	127.33	417.7
10°		573	8.681	174.6	114.59	376.0
11°		521	7.392	158.8	104.18	341.8
12°	Unit	478	7.236	145.5	95.50	313.3
14°	Chord	409	6.201	124.7	81.85	268.5
16°	-50.	358	5.426	109.1	71.62	235.0
18°		318	4.823	97.0	63.66	208.9
20°	Unit	286	4.340	87.3	57.30	188.0
24°	Chord	239	3.618	72.8	47.75	156.6
30°	-25	191	2.894	58.2	38.20	125.3

The moral effect of excessive curvature to deter travel- or rather, the moral effect of known excellence in that as in every other detail to encourage travel, is in not a few cases, - a consideration of more importance than appears. Advertising is generally regarded by all business men as a profitable outlay, even when it is all outlay. When the advertising is of such a nature as to in part pay for itself by saving expenses, even if only to a limited extent, it becomes of course still more desirable, and in the case of railways has the peculiar advantage noted in Chap III, that any additional sales they may thus make cost almost literally nothing.

In the case of some few roads which have an immense, an almost unlimited, traffic to contend for, this consideration alone may become of such great importance as to justify very heavy expenditure.

One of the "almost fanciful" expenditures referred to is to secure absolute perfection of appearance, as well as real excellance, in the track and right of way by dressing the edges of the slopes of the broken stone ballast to an exact line, stone by stone, and by elaborately neat and tasteful road crossings. Another, and the one more particularly referred to, is the expenditure of occasional large sums in bold lines to eliminate curvature and trifling amounts of distance.

The mechanics of curve resistance

The more essential facts are now tolerably well determined; but simple as the subject appears, the mechanics of a rolling truck on a curve is - to determine it correctly - a very intricate problem, the solution of which we must attempt to make clear.

The forces arising from the fact of curvature are of three classes:

1) Forces originating in and confined in their action to the truck itself, causing the slippage of the wheel on the rail which is the ultimate source of all curve resistance. The following two classes of forces can only act by augmenting or diminishing the former:

2) Centrifugal and centripetal force; acting upon the car as a whole and communicated to the truck through the centre-pin and side-bearing,

3) A force due to obliquity of traction originating within the train as a whole and communicated to the car-body and thence to the truck.

Curve resistance

1) Obliquity of traction and the length of the train have no appreciable effect to modify curve resistance.

2) Centrifugal force within the limits of practice has but little effect on the resistance, but that little is to increase it.

3) Centripetal force from superelevation within the limits of safe practice has but little effect on the resistance, but that little is to reduce it,

4) The best rule for superelevation is to elevate for the fastest regular speed up to a maximum limit of 6 to 8 inches in all,

5) Rail wear and curve resistance over rails in the same condition are as nearly as may be directly as the degree of curvature, with some minor elements which are independent of radius,

6) Rail wear and curve resistance are appreciably less with new rails than with old, and become greater as the outer rail is worn away to the shape of the flange,

7) The pressure of the flanges against the rail is the same on all curves independent of radius, but the wheel stands at a greater angle to the rail as the curve is sharper, and likewise is sliding faster on the surface of the rail as the curve is sharper, and likewise is sliding faster on the surface of the rail, increasing the danger of derailment correspondingly by some unknown amount, but not nearly in proportion to the degree of the curve,

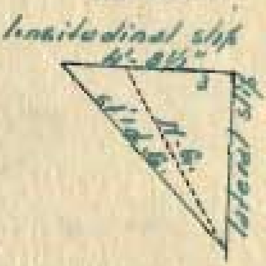
8) The lowest probable limit of curve resistance at ordinary freight speeds and in ordinary curves is about 1/3 lb. per ton per degree of curve, with all in perfect order. With worn rails and somewhat rough track it may be as high as 2/3 lb.per ton.,

9) While so obscure a point cannot be considered as established by the existing experimental evidence, all the more trustworthy existing evidence seems to combine with theory to indicate that curve resistance per degree of curve is very much greater on easy curves than on sharp curves; so that when the resistance is I lb. per ton on a 10° curve, and not more than 15 to 18 lbs. per ton on a 40° to 50° curve,

10) It may be considered established that curve resistance is affected somewhat by the speed, and probably by a very considerable percentage; to that if the curve resistance in motion be 1/2 lb.per ton it may be as high as 1 lb. per ton on worn rails, for speeds of less than 4 or 5 miles per hour, or the first train length or thereabout in getting underway. As a stoppage on any curve is always a possibility, this contingency should not be forgotten when reducing grade on curves, especially near possible stopping points.

11) The beneficial effect of the narrower gauge is small with the same length of wheelbase. With a 3-ft gauge as against a 4.7 ft.gauge, with a wheel-base of 4.7 ft., it is about as (not exactly as)

FIG.3



$$\frac{4.7^2 + 4.7^2}{3^2 + 4.7^2} = \frac{6.647}{5.576} = 1/6 \text{ less,as outlined in Fig.3.}$$

With a wheel-base of 29 the gain is only $\frac{110.72}{9736}$ = 12 per cent less. If, however, the length of wheel-base decreases with the gauge the gain is directly as the gauge.

12) Increasing the length of wheel-base,say, from gauge to 2 gauge increases curve friction as outlined in Fig 4. in the ratio of $\frac{2.236}{1.414}$ = 58 per cent.

FIG.4.

Having now investigated the nature of rail wear on curves and the causes of curve resistance, we are better prepared to take up and estimate at their true worth the positive objections to curvature, as summarized at the beginning of this Chapter, which are:

1) The direct cost of curvature of various radii; that is to say, the greater wear and tear of road-bed and rolling-stock, and the greater consumption of fuel,

2) The limiting effect of curvature on the weight and length of trains.

A moment's consideration will show that these two causes of expense are sharply defined from each other. For every curve, whether sharp or flat, and wherever situated, must cause a certain amount of wear and tear and waste of power, although it may not cause any shorter trains to be hauled, which is its direct effect on expenses; but if the curvature be very sharp or very unfavorably situated, or if the line be very nearly level so that there are no heavy grades to limit trains in advance of curvature, there will finally come a point where too much or too sharp curvature will not only cause wear and tear, but likewise cause the length of trains to be cut down.

The effect of curvature on operating expenses.

Fuel. About 33 per cent of the cost of fuel goes for getting up steam, kindling fires, running to and from trains, stopping and starting trains, standing idle, etc. and is hence a constant wastage, independent of the distance run. All of this may be considered as likewise unaffected by curvature, and in addition thereto is another and important source of loss, viz. condensation due to radiation of heat, which varies with the time of exposure, and hence with the distance run, but is in-appreciably affected by the power developed per hour. Every part of a locomotive, even the lagging, is hot enough to burn the hand in the coldest weather.

The fire-box is usually left entirely exposed, and the ends of the cylinders are protected only by metal plates. As a consequence, the average amount of fuel consumed in winter is about 20 per cent greater than in summer, or about 1 per cent for each 2°F. difference of temperature.

A particular form of bad practice in respect to curvature, and one of the most prevalent and indefensible of the minor errors of location, is a weakness for very long tangents and a readiness to spend money to secure them. A reasonably long tangent, say not less than 400 feet, is always very desirable, if not absolutely essential, in order to taper out the superelevation and afford room for proper transition curves; but beyond this there is no justification, theoretical or practical, for expending more than a very small sum to avoid any number of short and gentle curves. The difference in distance resulting from even very considerable and frequent breaks in a tangent is too trivial to be a serious consideration on lines of small traffic (although it may look as if it were considerable, especially on the ground), and the same is at least equally true of the curvature.

Many a tangent has been broken up improperly to effect less saving than this; but, on the other hand, a saving of 8000 to 10000 cubic yards of excavation is enough to balance it; and if we reduce the estimated traffic by two thirds or three quarters, in all ordinary country the saving by breaking up the tangent would far more than justify doing so, even in light work, for the above figures fully represent every measurable disadvantage from a moderately curved line of that character.

Especially if the general character of the work is heavy, the caution not to sacrifice efficiency for the sake of effecting trifling economies becomes of vital moment on such aligment if the most careful engineer would avoid error.

CHAPTER IX

Rise and Fall

The expense of gradients, as we saw in part in Chapter VI, arises from two causes, which are totally distinct and must be kept so to form any correct estimate of their cost or of their proper adjustment.

The first of these causes is the direct cost, for wear and tear and fuel of ascending to and descending from any given elevation, instead of running on a level; in other words, the cost of Rise and Fall.

The second objection to gradients is the effect which the maximum or rather ruling grade (since the ruling grade may, owing to the effect of variations of velocity, be either gre ater or less than the nominal maximum of the profile) has to increase the cost of operating the entire line, however short the ruling grade itself may be, not by increasing the direct expense per train-mile, but by limiting the number of cars to a train.

This latter objection to gradients (i.e. to one particular gradient, the worst one on the line) is vastly more important than the former, but it has no real connection with it whatever, being different both in its nature and in its effect in detail on the operating expenses.

Some time in the future the locomotive engine should be so improved, or such a new motor discovered, as to be able to exert an indefinitely varying power according to the need at various points on the line, all objections to both grades and curvature except such as is inherent in them - the resulting wear and tear and waste of fuel would disappear, and they might be introduced with great freedom; for neither of them would then have in addition to their own inherent disadvantages the further effect of limiting the weight of trains.

To some extent the cost of rise and fall, as well as the limiting effect of gradients, depends upon the rate of grade, for it must be divided as respect cost and disadvantages, into three quite distinct classes, according to the grades on which it occurs.

These classes are:

A. Rise and fall on grades so light or so situated as never to require the use of brakes nor variations in the power of the engine.

B. Rise and fall on grades heavy enough to require the slight use of brakes or shutting off steam, or both, in descending, but not such as to be a serious tax upon the engine in ascending.

C. Rise and fall on maximum grades, requiring the full power of the engine in ascending, with more or less use of sand, danger of slipping drivers, and the use of brakes in descending.

When a railway train descending a grade, or any other falling body, is acted upon by an accelerating force which remains uniform, - like the traction of a locomotive or gravity, - like the resistance of a train - the velocity of motion will continue to increase until the retarding force becomes equal to the accelerating, and thereafter the body will continue in motion indefinitely at a uniform velocity. The net resultant of all the forces acting is then zero, and consequently the body continues indefinitely in motion at an unvarying velocity.

From the interconvertibility of velocity and work results the fact - too little considered by engineers - that train resistance, in practical operation, (i.e. as measured by the tension on the draw-bar of the locomotive, or graphically recorded by a dynamometer) bears no very close and apparent relationship to what may be called the dead resistance, as determined by adding the nominal grade resistance to a certain rolling friction, without paying any regard to the effect of differences of velocity.

This is well understood by all those who have had occasion to deal with dynamometer experiments and is the greatest difficulty in deducing valuable results from such experiments.

Now the object before the engineer in laying out a railway is, obviously, to lay out his line so that the demand on the locomotive, and not the absolute grade resistance (which latter is in itself a thing of no moment), shall be as nearly uniform as possible, under the conditions which actually exist in the daily routine of operation. If, at a certain point, the velocity of the trains has certainly to be increased, in addition to overcoming the normal grade and rolling resistances, the gradient is in effect increased at that point. If at a certain other point velocity can safely be acquired before reaching it and then surrendered, the grades are in effect reduced.

The danger in using such a process as this as a basis for laying out grades is solely one common to most engineering and other work - bad judgment as to the practical possibilities and necessities. Thus, a stop may be required where one is not anticipated, or a velocity may be assumed which, owing to curvature or other cause, may not be practicable or expedient. The possible use of sand in starting or at particular points, or the varying power of the locomotive, may be forgotten, or a speed may be assumed at summits so low as to leave an insufficient margin for head winds and similar contingencies.

We have to remember that a train may be, as respects to its couplings, in three conditions:

1) In tension, its normal condition, which, whether greater or less, will only extend the springs a little more or less, but make no material difference in the whole length of the train,

2) In neither tension nor compression, the two adjacent cars tending for the moment to move with the same velocity, so that no force of any kind is

communicated from one to the other. This condition can only be momentary.

3) In compression, the cars behind crowding upon those in front.

In the transition from the first to this last condition lies the whole danger. So long as we do not pass the second (which is more properly merely a line of demarcation between the first and third) we are safe. Summarzing the preceding discussion of the nature of rise and fall, we have found that it may be divided into the following classes, having a very different effect on operating expenses:

Class A. Rise and fall on minor gradients and for small undulations, not sufficient to make it necessary to vary the power of the engine, but merely causing a momentary, gradual, and unobjectionable fluctuation of speed.

Class B. Rise and fall similar to class A, in its effect on speed, provided steam be shut off in descending, but not requiring the use of brakes in descending, nor seriously taxing the power of the engine on the ascent.

Class C. Rise and fall requiring the use of brakes in descending, in addition to shutting off steam, in order to avoid excessive velocities, and consequently, in almost all cases, more or less use of sand in ascending.

The cost of rise and fall.

Fuel. - Except as wasted by brakes, there is no loss of power (energy), and except as wasted by brakes and radiation combined, there is no loss of either fuel or power, from any amount of rise and fall of class A, if we neglect the slight difference in frictional resistances resulting from a (so to speak) regularly irregular speed instead of from a uniform speed averaging the same in miles per hour. This necessarily follows from elementary dynamic laws. Even if there be a difference in the level of the two termini, what power is lost in going in one direction is regained in returning.

When, in the case of rise and fall on easy gradients requiring no brakes (class B), we run a part of a distance of one or two miles (the ascent) under steam and another part of it (the descent)with steam shut off, assisted by gravity only, - or in other words, assisted by the energy stored in the train during the run over the up grade by the act of lifting it against gravity, - the total time that the locomotive is exposed to exterior radiation is the same, and probably also the loss of heat. The loss from interior radiation in the cylinders is a very important loss and we have to remember it. The loss by external radiation during the last mile will be a net loss.

From all these causes combined a locomotive running without brakes or steam down grades too steep to continue the steam-power unchanged, but not steep enough or long enough to require the use of brakes, will burn probably one fourth to one fifth more, and certainly not over one third more fuel in ascending one mile on the grade equal to the grade of repose (assumed at 26 feet per mile, or 0.5 per cent), and the descending one mile without steam, than in running two miles on a level. Allowing one third more, 80 vertical feet of rise and fall on such grades will waste fuel equal to the average consumption per mile.

When brakes are required, owing to the grade being either too steep or too long to permit of operating it without them, the power used in ascending is entirely lost, except that portion of it which is just sufficient to keep the train in motion on the grade of repose.

Repairs of cars and locomotives - The use of brakes is excessively destructive to wheels. Brakes, however, are used even more for stopping and starting than on grades - sometimes very much more and the whole cost of wheels is only some 30 per cent of freight-car repairs and very much less of passenger cars.

If we should consider only such facts as these, we might reach the conclusion that the wear due to grades must be a very important element in the cost of freight-car repairs, if all grades were levelled down flat so as not to require in any case the use of brakes, except for stops, wheel renewals would not be reduced more than one sixth nor car repairs as a whole more than one tenth. The only item of car repairs other than the wheels affected to an important extent is the cost of draw-gear and links and pins, and the loss in this respect arises more from lack of proper vertical curves at breaks of grade than from the grades themselves.

The cost of locomotive tires will be affected in much the same way and to the same extent as the cost of car wheels. The life of the boiler is likewise unfavorably affected by an intermittent instead of regular demand for power, although this effect is slight in comparison with the injury suffered from the cooling off of boilers at the end of the trip, from the effect of bad water and many other causes not connected with the grades between stations.

Wear of rails. - The effect of grades on the wear of rails is exaggerated in popular belief for want of a proper distinction between the effect of a heavy ruling grade, which increases the number of trains and the proportion of engine tonnage, and the effect of rise and fall simply on which the number of trains and proportion of engine tonnage is the same as on adjacent sections of level track.

Maintenance of road-bed and track.- In the former edition of this treatise the cost of these items was estimated as increased in about the same ratio as the rail wear, viz. 5 per cent for each 25 feet per mile (0.5 per cent nearly) of rise and as much for the corresponding fall. A liberal estimate in such a matter is proper, and we may continue the former estimate for class C, although it is probably somewhat too high for average conditions.

On class A and class B the disadvantages and advantages of the grade may be fairly considered to balance each other as respects maintenance of road-bed and track. A great compensating advantage from the grade, besides the lower speed, is the more perfect drainage, giving a firmer road-bed and prolonging the life of ties and ballast as well as preserving the surface. Creeping of rails is an annoying effect due in part to gradient, but has been largely done away with in recent years by improved forms of joints.

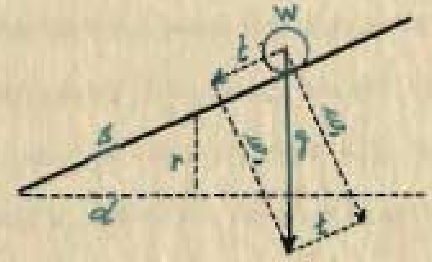
Train wages. - It is quite conceivable that one or more additional brakemen may be required on a line of much rise and fall, yet it would ordinarily be quite improper to include this as one of the expenses arising from it, for this reason: whether or not such additional force will be required is usually determined by the general character of the line beyond hope of change by the engineer.

CHAPTER X

The effect of grades on train-load.

The absolute effect of gradients to increase the load on the engine is constant and easily determined. Under the theory of the inclined plane (or rather under the general theory of the equilibrium of forces) any body W, (Fig.5), resting on such an inclined plane, is acted on by at least two forces: the force of gravity, vertically downward; and the reaction of the supporting planes, acting at right angles thereto.

FIG.5.



Since a body acted on by two forces only cannot remain at rest (see any treatise on mechanics) unless the forces are (1) equal in magnitude, (2) opposite in direction to each other, and (3) lie in the same right line, motion must ensue under these conditions down the planes; and the force t. necessary to resist motion is represented by the length of any line t.,which will suffice to close the triangle of forces. The direction of this force is ordinarily fixed by the conditions, and in the case we are now considering it must lie parallel with the plane s., as represented in the cut; but a force acting in any other direction, as t' or t", (Fig.6), will suffice for the same end, provided it will form with the forces g and w' (Fig.5), a closed triangle; the magnitude only of the force t. required varying thereby.

If the body W, be an angular body, this necessary force t will be supplied by the friction of contact between the body and the plane, and the body will remain at rest until the angle becomes very considerable, as in sliding a brick down a board. If the body be a wheeled vehicle, the journal and other rolling-friction subserves the same purpose, so far as it goes, as respects motion down the plane; but since the rolling-priction is a very small portion of the total weight of the body, the angle of the slope on which the rolling-friction alone will suffice to maintain equilibrium must be very small. When it does not suffice for this purpose, the body is impelled down the plane by the difference between the force t of gravity and the retarding force of friction.

FIG.6

When a body is caused to move up the plane it is obvious that the resisting friction, whether much or little plays no part in reducing the force t, tending to cause the body to move down the plane; for in that case the two forces resisting motion coincide with each other in direction, and their sum instead of their difference has to be overcome by the impelling force, whatever it may be.

These are the conditions under which the locomotive acts in hauling a train up a grade; and in Fig.5, if g be made to represent the weight of any vehicle W or all the vehicles, W' will represent the force with which they press against the rails; t, the "grade resistance" or force impelling them downward, or resisting motion upward; $\frac{t}{g}$ the ratio of the grade resistance to the weight, according to the number of pounds in the ton, the grade resistance in pounds per ton, $\frac{W'}{g}$, the ratio of the reaction against the rails to the actual weight of body, which may be deduced, for any grade.

All grades are, in the technical works of American and Continental engineers, expressed in the rate per cent, although in common American practice the words "per cent" are (somewhat unfortunately) omitted, the grades being known as a 0.5, 0.8, or 1.0 grade. A grade so expressed is independent of the particular unit of measure employed, whether feet, metres, miles, or any other. In popular American and English language grades are expressed by feet per mile, which (since there are 5280 feet in a mile) is 52.8 times the rate per cent. The use of this awkward unit, especially among engineers, is in every way to be regretted. English engineers are also much given to a still more awkward habit - expressing grades as rising "I in 80", or some other horizontal distance. These may be turned into grades per cent with a table of reciprocals. In Fig.5 the rate of grade is given by $\frac{r}{d}$. If we let d = 100 (whether feet or any other unit), then r will give, in the same unit, the rate per cent of the grade.

Since gravity, g, in the diagram of forces in Fig.5, is represented by the hypothenuse of a right-angled triangle, it follows that the pressure of the wheels on the rails, W', can never be quite equal to the weight of the body. The loss, however, is not on any ordinary grade a serious or even an appreciable one. It may be determined as follows:

Ration of pressure on rails to real weight $\frac{W'}{g} = \frac{d}{s}$; but $s = d^2+r^2$, exactly.

Or, approximately (1)

$$s - r = \frac{r^2}{2d};$$

Whence (2)

$$s = \frac{r^2}{2d} + d.$$

Comparing the two similar triangles, drs and w'tg, Fig.5, we have, since r: d:: t: w',

$$t = \frac{w'r}{d},$$

w' being, as we have seen, not the true weight or gravity of the body, but the component thereof at right angles to the plane, or the force with which it presses against the plane.

On any grade practicable for locomotives, however, w' and g are practically equal to each other, the difference even on a 10 per cent grade being only one half of 1 per cent, and on a 1 per cent grade (52.8 feet per mile) only $\frac{1}{100}$ as much, or $\frac{1}{200}$ of 1 per cent. Therefore it is universally customary to consider that for all practical purposes r: d:: t: g, whence

$$t = \frac{gr}{d}$$

The grade resistance in lbs. per ton = the rate of grade per cent x 20, OR = 2 lbs. per cent.

This last formula should likewise be indelibly engraven on the memory of the engineers having to do with railway work, making reference to a table needless.

From the preceding it follows that the effect of grades upon the grade resistance is directly as the rate of grade. On a grade of 1.0 per cent, the grade resistance is just twice as much as on a grade of 0.5; and by whatever percentage the rate of grade be reduced the grade resistance will be reduced as much.

To determine the effect of the grade resistance on the power of engines, the rolling-friction, a constant element per ton on both grades and levels, must first be considered, in addition to the grade resistance.

So far, we have considered only the gross weight of train, including engine; but it is apparent that the true measure of the cost of gradients is their effect upon the net or revenue-earning load of cars and freight, and the ratio of the net loads on any two gradients depends upon an additionable variable, viz., the ratio of the gross weight of engine and tender (or rather, of engine, tender, and caboose) to the tractive power of the engine. Whatever the absolute weight of the engine, if its ratio to the tractive power be the same, the ratio of the net loads will be the same on any two given grades, whether the engine be light or heavy.

For the gross weight of train on any given grade is directly as the tractive power, and if the ratio of the weight of engine to the tractive power be the same, the resulting net loads, as well as gross loads, will be to each other directly as the tractive power.

The percentage of change in the net load resulting from a change in the rate of any grade.

We can readily determine from the special table, in the manner below outlined, the two following laws, which are the foundation for a correct estimate of the value of reducing grade:

First. *When the rate of any one given ruling grade is increased or decreased, the corresponding percentage of increase or decrease in the engine-mileage required to handle any given tonnage varies almost directly as the change in rate of grade, however much or little the change may be, slightly increasing, however, as the increase is greater and decreasing as the decrease is greater.*

If the entire weight of the engine be considered a part of the train, this law is exact, regardless of the actual weight of the engine, and the engine-tonnage varies, precisely with the change in rate of grade.

Second. The amount of this percentage of increase or decrease in the engine-tonnage required varies considerably with each grade, being nearly five times as much on a level as on a 3 per cent grade.

Ordinarily the changes of grade which the engineer is called upon to consider are not very great. The typical percentage for any ordinary change in any grade, for use in estimating the value of a reduction or the cost of an increase, may therefore be taken to be that due to a change of 0.1 per cent in it. For extreme differences of conditions of any kind, the actual percentage of change in engine-tonnage should be directly computed from the relative train-loads.

CHAPTER XI

The effect of train-load on operating expenses

The effect on train resistance which results from an increase of ruling grade can be, and is, overcome in either of two ways: (1) by an increase in the weight and power of engines; (2) by decreasing the weight and increasing the number of trains.

The first of these - increasing the weight of engines - is by much the cheaper , but is only possible to a limited extent and under special circumstances ordinarily, it is not fair to assume that heavier engines are used on one alternate grade than on another, because, whatever advantage may be gained by using heavier engines on one grade may be equally well gained on the other grade. As it is far more frequently possible fairly to assume the use of heavier engines on heavier grades with passenger than with freight service, we will estimate the cost of each separately.

The cost of increasing the weight of engines.

The following items will not be increased at all by an increase of weight of engines to suit the requirements of a higher grade, the weight of train remaining the same: The cost of (1) repairs of cars; (2) train wages; (3) general expenses; (4) maintenance of way and works, exclusive of rail and tie renewals and lining and surfacing; (5) that portion of the maintenance of way expenses last expected which is caused by the cars and not by the engines.

The most reasonable estimate which can now be made of the relative effect of engine and cars upon the track is that considerably over half of the deterioration of track comes from the passage of engines over it, and the remainder only from the passage of cars, which may weigh ten or twenty times as much. Assuming one half only, we are led to the conclusion that more than three quarters of total expenditure is unaffected by an increase of the weight of engines in any visible and direct way.

The effect on cost of maintenance of track of increasing the weight of engines has been greatly modified and much reduced since the publication of the first edition of the volume (prepared, as it necessarily was, from records which were some years old in 1876) by the now universal use of steel rails in place of iron. The causes and extent of the changes thus brought about have been already summarized before. The most important of all, as respects the use of heavy engines is that the nature of the wear of rails has changed. With iron rails, the wear took the form of a crushing or lamination, which destroyed their surface long before the direct abrasion had become a serious matter. This crushing was very greatly hastened by heavy loads per wheel, and increased in much faster ratio - to the extent that iron rails which would sustain the passage of light engines for many years would be crushed out by heavy engines in a few months. On the other hand, with steel rails (excluding those of inferior quality, of which far too many have been and are laid) the wear is merely direct abrasion, which is not materially increased per ton by train either by load per wheel or speed. As respects the last at least, there is very good reason to believe that it increases in much less than direct ratio.

Of the remaining items of the cost of track, lining and surfacing, in spite of apparent reasons to the contrary, is effected by increased weight of engines in a considerably greater ratio than the rail wear, and tie renewals to a very considerable extent, although not quite so largely. We may not improperly take half the total cost of rails, ballast, ties, adjusting track, and switches, frogs, a$_n$d sidings, as varying directly with the average weight on drivers, car-tonnage being constant.

The remaining items of maintenance of way, for Bridges and Buildings, are very slightly affected, certainly by not more, in ordinary cases, than 1/4 ct. per train-mile, the whole being an allowance for interest and maintenance charges on heavier bridges.

Repairs of engines are affected much less than would be supposed by the weight of engines.

The remaining expenditure, for raw materials and for wheels, axles, and tires, will vary nearly, but not quite, directly as the weight.

It would appear from these facts that 50 per cent of the cost of repairs may, with sufficient exactness, be assumed to vary directly with weight of engines, the remainder being constant, as has been stated before.

The cost of fuel for heavier engines hauling the same train behind them will not be largely increased. In not a few cases there would be an actual decrease. It is to be remembered that, even if heavier engines are used to overcome a somewhat higher grade, it is only for a short distance that the extra power is required. On all up grades below the maximum, and in descending all grades, the power required and exerted will be no greater than with the smaller engine, except the slight addition due to the weight of the engine itself, and this power will be somewhat more economically exerted, owing to the heavier engine being less pushed.

For all these reasons together, on something like two thirds of the length of ordinary railways the fuel burned per mile would be but slightly, if at all, affected by moderate (not over 20 per cent) differences in weight of engines, and on the remaining distance not more than 50 per cent of the fuel burned would vary directly with the weight and power exerted. As an average of entire runs, it is entirely adequate to assume that 25 per cent of the total fuel consumption varies directly with the weight of engines hauling the same train over for the most part the same grades, and the remaining 75 per cent is unaffected. On this basis, an engine 20 per cent heavier would average for entire runs not over 5 per cent more fuel to haul the same trains. The cost of supplying oil and water would vary in about the same proportion.

The cost of increasing the number of engines to haul the same traffic, on account of a heavier grade, may be estimated as follows:

The number of trains is supposed to be increased by a change of maximum grade only, which will not ordinarily extend over one third of the distance. While running over the remaining distance, the work done on the train behind the engine will vary according to the weight or number of cars. While running on the maximum grade the power exerted by the engine will be the same, since in each case the engine is supposed to be fully loaded on that grade.

Fuel.- For reasons already enumerated, about one half of the consumption of fuel will vary directly with the tonnage of the train; the other half, consisting of the fuel burned in stopping and starting (in part), getting up steam, loss by radiation, loss by head resistance, etc., making up in the aggregate the 50 per cent which is unaffected by the length of the train.

If, therefore, the maximum grade be increased on about one third the length of the road, while on the remainder the grades remain about the same, about one half the consumption on two thirds of the distance, equal to all the consumption on one third of the distance, or 33 per cent of the entire consumption will vary directly with the net weight of the train, so that, if the grade were so increased as to take two locomotives instead of one to handle the same traffic, the fuel consumption would be as 1.0 to 1.67 at most, and not as 1.0 to 2.0, as might be over-hastily assumed. The aggregate cost of oil, waste, and water will vary in about the same proportion.

Train-wages will of course vary directly with the number of trains, unless the change of grade in contemplation were so great as to shorten up trains so as to dispense with one brakeman, which can rarely happen.

Station, Terminal, and General Expenses will remain unaffected by any moderate change, but there is nothing by which they are so quickly affected as by a decided increase in the number of trains, and a full 20 per cent of their aggregate may be considered as varying directly therewith.

Engine Repairs should apparently vary directly with the miles run; but the indications are that as a matter of fact it is much less likely to do so than maintenance of way, owing in part to the large proportion of incidental expenses which are not by any means doubled to maintain a double number of engines. There will also be a certain diminution of wear and tear from stopping and starting, etc., from the fact that the trains to be handled are shorter. Taking both of these causes together, it is not probable that doubling the number of engines to move the same number of cars would increase engine repairs in the ratio of more than 1.00 to 1.75, and probably somewhat less.

Car Repairs are certainly affected beneficially by having a less number of cars to a train. By referring to the table below, it will be seen that more than one third of the total cost of car repairs can be directly traced to the concussions of stopping and starting and making up trains. Much of this expense may disappear with the introduction of better couplers; but even this is doubtful, as an automatic coupler will permit of much more violence in running cars together, since a brakeman's life between the cars will no longer have to be considered. A diminution of at least 10 per cent may fairly be estimated as a result of running only half as long trains.

TABLE V

Distribution of the cost of Freight-Car repairs to its various contributing causes

Item	Total Cost of Item	Distribution: Effect of Time and Age, independent of Work and Mileage	Distribution: Stopping and Starting	Distribution: Terminal: Making up Trains, etc.	Distribution: Curvature and Grades	Distribution: Distance only between Stations on Straight Track
	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.
Wheels	30	---	5	2	13	10
Axles, brasses, and boxes	30	---	5	2	5	18
Springs	10	---	2	1	1	6
Truck frame & fittings	5	2	1	1	---	1
Brakes	5	---	2	1	2	---
Draw-bars	10	---	4	4	2	---
Sills & attachments	5	1	2	2	---	---
Car-body, painting, etc.	5	3	0.5	0.5	---	1
Total	100	6.0	21.5	13.5	23.0	36.0

To these expenses, properly so called, is to be added an interest charge on the cost of the additional motive-power required by the higher grade, unless the first cost of these engines be included in the estimated cost of constructing the higher grade-line, before determining the difference in the capital investment.

This should be done because the addition of the required number of engines is really so much added to the original investment. Before the line is ready to handle the required traffic it is as necessary to have them as it is to hafe the track laid on the high grad-line and not on the other. In considering differences of distance (if not too great), or curvature, or rise and fall, this is not so. The total amount of equipment will be the same whatever the differences in that respect. We therefore estimate the expenses regardless of interest on the plant, and only consider differences in the cost of construction. Of the car equipment the same is true in the case of gradients. Whatever the grades, the number of cars will be the same; but as the number of engines is increased becaused of the grades, and not for any difference of traffic, we must either include the difference in the cost of equipment as a part of the cost of construction; or add an interest charge to expenses. On the whole, it is more convenient to add the interest charge.

Putting together all these items which have been just considered, we obtain the summary given in Table VI, as the effect on operating expenses of so increasing the rate of grade as to double the number of engines required to handle a given traffic. When and if it can be fairly assumed that the weight of engines can be increased instead, Table VII gives the percentage of increase in expenses.

TABLE VI

Estimated Average Cost per Train-mile, of Doubling the Number of Trains to handle a given Traffic; or Proportion of Expenses which varies directly with the Number of Trains, the car-tonnage remaining Constant.

Item	Average Cost of Item. Cents or Per Cent.	Per Cent Added by Doubling Number of Trains	Added cost. Cents or Per Cent.
Fuel	7.6	67 per cent	5.1
Oil, waste, and water	1.2	"	0.8
Engine repairs	5.6	75 per cent	4.2
Switching engines	5.2	Unaffected	---
Train wages and supplies	15.4	100 per cent	15.4
Car maintenance and mileage	12.0	10 p.c. <u>less</u>	(- 1.2)
Renewals, rails	2.0	100 per cent	2.0
Adjusting track	6.0	"	6.0
Renewals, ties	3.0	"	3.0
Earthwork, ballast, etc.	4.0	"	4.0
Switches and sidings	2.5	"	2.5
Bridges and buildings	5.5	Unaffected	---
Station, terminal, and general	30.0	20 per cent	6.0
Total of operating items	100.0	47.8 per cent	47.8

To this is to be added the interest on the cost of one extra locomotive for one train-mile. Estimating the cost of the locomotive at about 10,000 times the cost of a train-mile

	Brought forward	47.8
and the interest thereon at 6 per cent as about 600 times the cost of a train-mile; and estimating the average passenger-engine mileage to be 40,000 miles per year, we have, as the interest charge, per mile		1.7
	Making the grand total	49.5

TABLE VII

Estimated Average Cost per Train-mile of Doubling the Weight of Engines to Haul the Same Train

Item	Average Cost of Item. Cents or Per Cent.	Per Cent Added by Doubling Weight of Engine	Added Cost Cents or Per Cent
Fuel	7.6	25 per cent	1.9
Oil, waste, and water	1.2	"	0.3
Engine repairs	5.6	50 per cent	2.8
Switching-engines	5.2	Unaffected	---
Train wages and supplies	15.4	"	---
Car maintenance and mileage	12.0	"	---
Renewals, rails	2.0	50 per cent	1.0
Adjusting track	6.0	"	3.0
Renewals, ties	3.0	"	1.5
Earthwork, Ballast, etc.	4.0	"	2.0
Switches and sidings	2.5	"	1.3
Bridges and buildings	5.5		0.3
Station, terminal, and general	30.0		---
Total	100.0	14.1 per cent	14.1

TABLE VIII

Estimate of the Value of Reducing Grades on French Railways (By M. Ricour, Ing. en Chef, Corps des Ponts et Chaussées.

Grade	Gross Load C. Tonnes	Price per Train Kilo Francs	Price per 1000 tonnes gross, per Kilo Francs	
.4	568	1.546	2.72	Diffs
.5	487	1.465	3.00	.28
.6	425	1.403	3.30	.30
.7	375	1.353	3.60	.30
.8	335	1.313	3.91	.31
.9	302	1.280	4.23	.32
1.0	274	1.252	4.56	.33

TABLE VIII (Cont'd)

Grade	Gross Load C. Tonnes	Price per Train Kilo Francs	Price per 1000 tonnes gross, per Kilo Francs	
1.2	230	1.208	5.25	.36
1.4	196	1.174	5.98	.37
1.6	169	1.147	6.78	.39
1.8	147	1.125	7.65	.46
2.0	131	1.109	8.46	.43

The proportion of traffic affected by the rate of ruling grade

According to the character of the road, this may vary under certain conceivable circumstances between the extreme limits of 0 and 100 per cent, for both passenger and freight traffic. Freight traffic is by far the most affected, but there are at least occasional instances in which the freight traffic is so light and so little liable to grow that no appreciable value whatever can be assigned to reduction of grades below a certain limit. For, as the whole objection to gradients, properly so called, lies in their effect to limit the length of trains, a reduction of their rate has value only for such trains as they do in fact so limit. One train at least, the "way freight", is very often not so limited on all railways, and many minor railways are not so fortunate as to run anything else but way freight over their lines.

As respects passenger business, although it is much less directly and immediately affected by a change of grade than freight traffic, because of the higher speed, and the large surplus of motive-power required therefor and for stopping and starting, yet in the long run, whenever the passenger business becomes considerable in volume or largely competitive, either the number or the weight of passenger engines must be materially affected by the rate of grade. The effect in the case of passenger traffic is far more irregular, but not therefore the less certain. A train, for example, might haul an extra car or two over any given grades, or haul the same cars over a heavier grade, as well as not, when the addition of yet another car to the train of say ten cars might require to be cut in two, and so immediately double the motive-power required by increasing the load hauled only ten per cent. It is certain, moreover, that, whatever the margin of power deemed necessary for emergencies, if we reduce our grades and train resistance by any fixed amount, the weight of engines may always be reduced, or the weight of train increased, in the same proportion, and yet leave the same margin for emergencies or anticipated growth of traffic as before, however much or little that may be. Hence a reduction of ruling grade has a positive and present cash value, even if every passenger train on the road will habitually run light for an indefinite number of years.

Keeping all these considerations in view, the effect of change of grade on passenger traffic may be summarised as follows:

For roads having considerable passenger traffic, say over four or five trains per day each way, the passenger trains will be affected essentially as freight trains are, unless the ruling grades are short and undulating, and the estimated number of each class of trains should be added together.

For roads having only one or two light passenger trains per day run at no very exacting speed, the passenger traffic may not be affected at all by a moderate change of grade. Whether it is likely to be or not, must be determined by tables.

For such ordinary passenger traffic as most new American roads look forward to in the near future, say from two to five trains per day, half the estimated number of passenger trains may be added to the freight, for estimating the value of reducing grade, for the reason that at least half the trains are liable to be affected by the gradients.

For still another reason than those just mentioned, it can rarely be essential to enter into minutely accurate calculations as to the minor details to decide on one line or the other. When the comparison between two lines becomes so close that it would otherwise be necessary, the possible effect of the two lines on volume of traffic ought alone to outweigh it, and the prudent rule becomes -

1) When the company is or soon may be poor (and it is no more than common prudence to assume that it will be embarrassed for means at some time in the near future, when it is not backed by a great system of profitable lines in operation), take the line of lowest first cost.

2) When immunity from financial embarrassment is assured, take the line which offers the most promising conditions for future growth of traffic.

3) Only when the two lines are substantially equal in both these respects enter into such minute calculations as these just suggested, and whichever line be selected no serious harm can then result.

Having determined the justifiable expenditure to obtain low grades, we have only taken the first step toward their proper adjustment. Some of the worst sacrifices of gradients are made without effecting any saving of cost whatever, simply from inattention to its importance, or from attaching exaggerated importance to losses of distance or curvature, or from insufficient study of the topography, leading to a too hasty conclusion that all has been done which can be done, when in fact a very little study would lead to far better results.

This question of how to get the lowest grade which the region admits of, at a given cost, has been discussed before.

The four following sub-departments of the general problem of gradients yet remain to be considered:

1) The use of assistant engines with high "bunched" grades,
2) The balance of grades for unequal traffic,
3) Limiting curvature, and the proper compensation therefor,
4) The limit of maximum curvature.

These questions we will consider in their order.

CHAPTER XII

Assistant Engines

The general use of assistant engines, commonly called pushers. As recently as 1873, Gen. Herman Haupt, in a paper on gradients, felt compelled to say that he was making "an attempt to prove, contrary the generally received opinion" and"that the use of higher gradients for part of a given distance will often result in greater economy of operation than a lower and uniform gradient for the whole distance".

The adoption of the opposite policy, attempting to get a line of a low uniform gradient through a country of any difficulty whatever, is very apt to be enormously expensive, and to be possible at all only by frequent undulations, considerable detours, and much higher gradients over most of the line than there is any necessity for using. This results from the fact that it sets at defiance one of the broadest and most nearly universal laws of physical geography, - to which there are few and rare exceptions on the whole face of the globe - that long stretches of easy plains or gently sloping valleys penetrate at intervals to and into the very heart of even roughest regions, leaving short sections only over which high gradients are unavoidable. By following these easy routes as long as we can we accomplish over most of our line three desirable ends at once:

1) We get the cheapest line,

2) We get the lowest through grades; and,

3) More than all else, *we concentrate the resistances* into the remaining more difficult section, so that the motive-power on it can be accurately adapted to the work required and kept fully at work over the distance where it is used, thus making it almost a matter of indifference

what rate of ascent we adopt on our more difficult sections (Fig.7).

Even where we are unable for any reason to follow the valley lines which usually penetrate far into hilly or mountainous regions, as for instance when the valleys are impracticable, or are less practicable than the ridges, it is still true that pusher gradients will almost invariably fit the country better. The all but universal low of topogeography is that, when the ground is not a dead level, transitions from one level to another, whether on a large scale or on a small scale, are of the form shown in Fig.8 and 9. If on a small scale, we may simply adopt the dotted profile AB, and make the fill at C or cut at B. If on a larger scale, say for a total rise of 50 or 60 or 80 feet, it becomes impossible to do this, especially if the necessity occurs at many points, and we are reduced to adopting the profile ACB, making BC the ruling grade of the line, or else to one of the two expenditures

FIG. 7

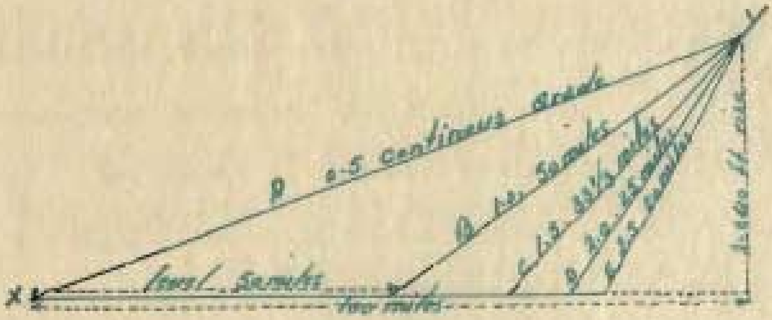


FIG.8.

Fig.9.

shown in plan in Fig.9 - either to run right over the obstruction with almost a tangent-line, giving the dotted profile AB, in Fig.10, or to sacrifice curvature and distance and obtain the full-line profile. The first has been done to a most unfortunate extent in the prairie lines of the West; the last is almost always the proper course, if it saves an increase of ruling grade, even when necessary at many points on the line.

FIG.10

The secret of the vast economies which may often be realised by the skilful use of assistant engines is this - that as respects construction we work with nature instead of against her, and that as respects operation we gain a like advantage by keeping every engine while running fully at work, the greater portion of the hard work in foot-pounds being done on a small portion of the division, with such favorable through grades, in many cases, that there is little more need for an engine on the remainder of it, than to keep the longest trains moving and under control.

The advantages of the use of pusher grades are not at all confined to high grades, but on the contrary are even greater proportionately for low grades, provided only that there be business enough to fill up the trains, and couplings good enough to permit of handling long trains. On roads of light and irregular traffic there may be no great advantage in them; but many roads having large traffic, which must be hauled cheaply because it pays little, are habitually using pushers on gradients as low as 0.5 to 0.6 per cent.

The power of assistant engines

By the use of assistant engines the available motive-power is approximately doubled or trebled; and it is evident that economy in motive-power requires that the rates of these grades should be proportioned to each other as nearly as possible, in order that neither grade may be disproportionately low, but that the true ruling grade may be - not necessarily either the higher (pusher) grade or the lower grade, but that one which involves most difficulty and expense in reduction.

With certain provisos which we will shortly consider, the determination of a practically exact balance of gradients for the use of one or more assistant engines is a simple matter. If the assistant engine be of the same weight as the through engine, the load to be hauled by each engine is reduced one half. If there be two pushers, the load to be hauled by each engine is reduced to one third of what it was.

The grade on which the through engine can haul that per cent of its load on a given through grade will therefore be the corresponding pusher grade for pusher engines of such weight.

The economy will ordinarily dictate, therefore, that the resistance of the pusher grade should be at least ten per cent less than an apparent balance requires if attainable at moderate cost, with the following proviso:

If the rate of the pusher grade be, from its cost or otherwise, the fixed element beyond control, as often happens, then the rate of the lower through grade should be reduced at any reasonable cost (it is usually more at the cost of care than money) to and a little below the full extent which an apparent balance requires; in accordance with the sound general principle, that the links in a chain whose strength we cannot control nor exactly foresee should be the weakest, and not those whose strength we can control and can foresee.

A variation in the weight and power of the assistant engines affords a mean of equalizing minor inequalities in the balance of gradients, should such be discovered, but this should be counted on with caution in original location.

To count on using pusher engines lighter than the through engines would ordinarily be very bad practice. It would be preferable to save money and length of pusher grade by using a steeper rate of grade.

The duty of assistant engines

1) When traffic is very light, pusher grades, if not too long, may be operated by cutting trains in two, leaving half the train at the bottom of the grade, placing half of it on a siding at the top, returning for the other half, which is preferably pushed up, and then proceeding, after coupling up, with the entire train once more,

2) At short pusher grades near stations, yard or switching engines can often perform a part or all of the required pushing service at very moderate cost - or, what amounts to the same thing, the pushing engines can be so utilized for switching service as to greatly reduce the cost and inconvenience of using pushers.

The instances are many where yard engines are utilized in this way, if only to help trains through yards at which there would be no difficulty, except for the fact that it is a yard, because, for obvious topographical and commercial reasons, it is very common to find large yards near short stretches of objectionable gradients.

The convenience of the service must be considered a-s well as the theoretical requirements in estimating both the probable duty and probable cost of the assistant-engine service, as also of course in laying out the grades. Unless a station be situated immediately at the foot or top of the grade, the service must be assumed to begin at the nearest considerable station, if there be one within three to five miles of either point, because that is where convenience will require that it should begin in practice.

No stop is required at the top of the grade for uncoupling the pusher, but for coupling on a stop is necessary, and a single stop of a heavy train costs more than a five - or even ten - mile run of a light engine, which would otherwise be standing idle with steam up.

The cost of assistant engines

This may be divided into three elements:

1) Interest charge on the original cost, special to the use of pushers, including extra engines, engine-houses, if any; sidings; block signals, if any, etc.

2) Cost per day for wages and a certain portion of the fuel and repair charge all of it independent of the mileage run per day, as is also the cost of maintaining block signals, if any.

3) Cost per mile run for fuel and repairs,and for wear and tear of road-bed, track, and sidings.

The maintenance-of-way expenses must also be estimated at a considerable figure.

Accurately to estimate the cost of pusher service, then, we must determine:

First: The length of pusher run in miles,

Secondly: The probable number of daily trips per engine, and hence the number of engines required for the given traffic,

Thirdly: Determine the annual interest on their first cost,

Fourthly: Compute the cost of the mileage made, according to parts.

The sum of the last two items will be the total cost of the pusher service.

With reference to the passenger business on this particular line, if only a moderate through traffic is to be handled, the difference in the gradients will be, with well-arranged stations, a matter of little consequence. If only a little heavy passenger traffic is to be handled, under otherwise favorable conditions, the uniform gradient of 1.25 per cent will have a certain advantage; but if any really heavy passenger traffic is to be handled, the pusher line will have much the same advantage for it, and for much the same reasons as it has for the freight traffic. It is a much more indeterminate problem, but the financial importance of high passenger speeds at all points and the effect upon it of low gradients and easy curvature is generally over-estimated.

PART III

LARGER ECONOMIC PROBLEMS

CHAPTER XIII

Trunk lines and B-ranch lines

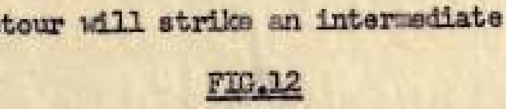
That the most elementary conditions on which the success or failure of railway enterprises depend are often radically misunderstood, almost necessarily follows from the fact that the world is so full of examples of misdirected enterprise - of lines built with great hopes of profit which have proved miserable failures; while, on the other hand, there are so many example of roads built for local purposes, or otherwise without particular expectation of a brilliant future, which have proved magnificent properties.

Let us suppose a railway to be projected, say 100 miles long, to connect two traffic points of some important, A, B (Fig.11). We will assume for simplicity that there is little or no intermediate local traffic, as often happens. We will consider A and B to be equal, not necessarily in population, but in traffic-contributing capacity to this particular line. The traffic which the railway has to support it may be then represented by the combination AB, being that which naturally exists between two traffic points of the importance of A and B.

FIG.11

Let us now suppose that another alternate route may be chosen which by a slight detour will strike an intermediate traffic point C, (Fig.12) of

FIG.12



equal potential magnitude with A and B how have we affected the revenue-earning capacity of the line?

A most natural answer - beyond all question a very common answer - is that we have increased it just 50 per cent. Instead of serving perhaps 100,000 people in the two towns A and B, we now serve 150,000 people in the three towns A, B, C. Fifty per cent more people, fifty per cent more traffic, fifty per cent more earnings - seem natural corollaries of each other.

On the contrary, it may be shown at once that we have doubled our probable traffic, and really we have tripled our traffic, and rather more than tripled it. Instead of having only traffic AB, (Fig.11) we have traffic AB, Traffic AC, Traffic CB (Fig.12).

The value of the latter is obviously twice, and really considerable more than three times, that of the former.

To have the traffic tripled we must assume that Traffic AB, Traffic AC, and Traffic BC, (Fig.12) are of equal financial value - which they are, as nearly as may be.

An objection to this statement will naturally suggest itself - that in Fig.12, although the traffic points A, B, C are equal in magnitude, yet the Haul on the Traffic AB is twice that on Traffic AC or CB. Therefore, if the volume of each be the same and the rates be the same, we apparently have Traffic AB = Traffic AC + Traffic CB, so that we have only doubled instead of tripling our traffic from a revenue-producing point of view.

But these latter assumptions are not correct, either as respects the volume of or rates on traffic.

As respects the effect of distance, it may be said in a general way that, if we consider only great and decided differences of distance, the volume of traffic, both passenger and freight, will be at least inversely as the distance: that is to say, if two given traffic points 100 miles apart, could be moved up to a distance of only 50 miles from each other, and remain otherwise unchanged, the volume of traffic between them will be at least doubled.

We see, therefore, the reasons why, assuming the points A, B, C, to be of inherently equal traffic-producing capacity, the short-haul traffics, AC and CB, should each one of them be of more rather than less value than the long-haul traffic, AB; from which it follows that the aggregate of the three traffics AB, AC, CB, (Fig.12) will be worth more rather than less than three times as much as the traffic AB alone.

This being determined, let us now extend the inquiry by determining, in the same manner as above, the probably comparative traffic on five different lines of any common length, Figs.11, 12, having two, three, four, five, and six traffic points on them, each point being assumed for the sake of simplicity, to be of equal traffic-producing capacity.

FIG.13

FIG.14

FIG.15

Fig.16

Comparing Fig.11 with Fig.16 by multiplying our traffic points by three we have multiplied the traffic by fifteen, or have increased the productiveness of each separate traffic point five times.

Trunk Lines.

Trunk or main lines may be roughly divided into two classes: those which are, and those which are not, liable to be subjected to close competition at almost every important point.

Almost all lines in the United States belong to the former class. Their only permanent protection against competition, in most cases, is to throw out a shirmish-line of branches and parallel routes so as to cover securely a considerable territory; and this is one great reason for the tendency in that direction which is so notable, and which has already gone so far that more than half the mileage of the United States is controlled by a dozen managements, with every prospect that the tendency to consolidation will grow still stronger.

Nevertheless there are certain mountainous or sparsely populated and poor regions, in this and all other countries, where reasonable freedom from competitive lines is assured, as in Mexico, the lines in which afforded some instructive examples of the right and wrong way of laying out main lines.

Bearing in mind what we have already seen as to the small expense of operating extra distance, the appreciable additions to revenue which may be expected to arise from it, and the small effect of moderate additions of distance to discourage traffic, there can be no question that the fundamental rule for laying out such lines - deviated from only for good special reasons - should be to link together the largest possible population, regardless of minor losses of distance, provided the <u>aggregate population per mile of road</u> is not diminished, or even sometimes if it is. An ultimate limit, beyond which it would certainly be unwise to go, and hence which should not be closely approached, is that the increase per cent of distance should not exceed the increase per cent of probable revenue.

The most marked exception to this rule is when the difference of distance becomes so great as seriously to discourage traffic, or encourage the construction of a more favorably situated competing line.

A further exception is when, by passing midway between two traffic centres, neither of which can be reached readily by the main line, both may be served fairly well by branches or otherwise.

Trunk lines open to destructive competition, and able to command only a narrow belt on each side of them as their natural tributary territory, nor that, unless they afford almost as good accommodations as it is possible to give, can of course afford no such sacrifice as this.

We may summarize a few of the more important conditions of success as follows:-

1) They must reach by their own lines the largest traffic point at each end which is at all within reach by an extension of 20 or 30 per cent of their length, and there must stand on equal terms with their connections as respects benefits and injuries to be given and received.

2) They must reach without fail every considerable intermediate traffic point along their line which can be reached by any reasonable detour or even sacrifice of grades, their prosperity being about as the square of the tributary population.

3) They can in no case attempt to create new channels of trade, as by attempting to make a seaport out of some neglected roadstead, without the greatest risk of failure. The attempts in this direction have been many; the successes as yet none.

4) Nearly or quite half of their traffic must practically begin and end on their own lines, either because it goes no farther, or because it is delivered at some great competitive distributing point.

5) It is of little avail to run a line even from a great city to

nowhere. The apex to the pyramid is eloquent and truthful in this respect. Without a good traffic-point at each end of a line the conditions for great prosperity are not present.

Branch Lines

That branches are in the main profitable investments is evident from their very rapid rate of increase, which is largest, up to a certain point at least, on the most prosperous lines. That they are rarely very profitable when considered by themselves, and apart from the main line, and as a rule do little more than pay operating expenses, is abundantly shown by the reports of almost every line which has branches and reports their traffic in detail. This fact is so clear and so generally admitted, that it hardly needs statistics to prove it. As a rule, the earnings per mile of branches range only from a fifth to a tenth of the earnings of the main items.

It is not to be wondered at, therefore, that branches and extensions are much sought for by prosperous companies, even in regions where there is not the likelihood of rapid increase of traffic which prevails throughout the United States. Neither is it to be wondered at that the seeking for them is often overdone, so that the branches become a burden which threatens to swamp the main line, and often does so. For there is this to be said against branches.: their traffic is usually thin, while they cost as much or more to build and not much less to keep up than the main line.

Therefore it is easy to lose all that is gained on the main line by the extra cost of handling the traffic on branches and paying their rentals; although it still remains universally true, that branches are far more profitable than appears on the face of their returns, separately considered.

These facts make it easy to see what should be the governing rule in laying out branches. The one universal rule, to be deviated from only when special reasons to the contrary appear, is this: Strike the main line as soon as possible. In laying out a branch to A from the main line ED (Fig.17) (which represents to scale an actual instance), B is in all ordinary cases the point to strike the main line, if possible, even at some disadvantage in grades and construction. It is not correct to compare the entire line ABCD with the alternate ACD. Were we building a line to handle a main-line traffic between A and D, that would be the proper course to propose; but with branch-line traffic, when we have got it to the main line we may say, for preliminary and approximate purposes, that we shall handle it thereafter for nothing.

Branch-line traffic is light and fragmentary. Grades and curves then become minor considerations within pretty wide limits, especially when one, two, or three engines must be kept on the branch anyway. On the other hand, the extra cost of keeping up the track on AC instead of AB is so much dead loss.

Any traffic AE is seriously burdened by the additional distance via ACE over ABE, while the gain to the traffic AD is but trifling.

Passenger traffic is almost invariably better served if delivered on the main line with the shortest possible haul.

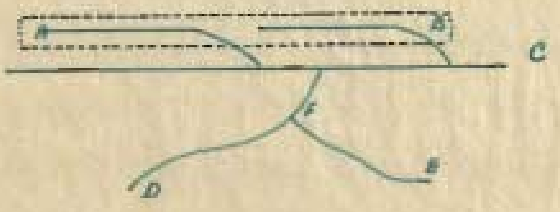
It is therefore bad practice to lengthen out branches to get cheap construction and good grades, even when the difference favors most of the traffic of the branch, unless the extension is justified by the cardinal rule laid down: by which route is the traffic delivered on the main line at any point, most cheaply and advantageously, regardless of where?

To the preceding is to be added another still more important and sometimes conflicting rule: Strike the main line at a considerable town, if possible. If there be a town of some size at either B or C (Fig.17), that will be the point to terminate the branch at, or to consider it to terminate in comparing the alternate routes, for the traffic of the branch will be very apt to be delivered at this town even if the branch strikes the main line elsewhere, if it does not add more than 20 per cent to the haul.

When the purpose of the branch is not to reach any particular point, but to develop a tract of territory, the conditions are of course somewhat changed, but even then the same general principles apply. It will as a rule be more economical, and more convenient to the traffic, to concentrate it upon the main line as soon as possible. Therefore it is not as a rule good practice, even when the purpose of the branch is to develop a long strip of parallel territory which has traffic relations mostly in one direction, C, (Fig.18), to construct branches along parallel lines. The method outlined in Fig.19 is far more likely to accomplish its purpose advantageously, even when branches like D E F become necessary; the governing rules being, first, to link together neighboring towns having

FIG.18

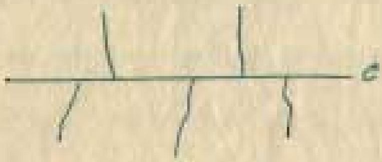
FIG.19



natural traffic relations as directly as possible, and secondly, to reach the main line quickly.

When the traffic of the branch is equally divided between East and West, or nearly so, as respects destination on the main line, then Fig.20 gives what is abstractly by much the best system for laying out branches other things being equal. Other things rarely are exactly equal, and hence considerable deviations from this plan are often required in the laying out of such branches, but in all cases branch traffic needs to be quite differently considered from what it would be if we were laying out a main line to the same point.

FIG. 20



CHAPTER XIV

The improvement of old lines

It should follow from what we have already seen in respect to the errors which may be committed in the laying out of new lines, that many existing lines, built in haste and without adequate study of conditions of greatest economy, should be capable of material improvement at a cost far within the added value to the property. That this is so is a matter of common observation and belief, and many lines are already acting upon it to their great advantage. Undoubtedly the number of such lines will continue to increase, influences by the sharp spur of necessity if nothing else, and it is probable that this would be more generally done if it were fully realized what great improvements may, in cases, be effected at very moderate cost, and how readily the possibilities in that direction may be determined without elaborate and costly surveys.

The subject is one which usually requires careful study, not so much for determining whether or not improvements can advantageously be entered on, which is often too clear for doubt, as for determining precisely how and where the most improvement can be effected for the least money, so as to avoid the danger that, if the improvements are entered on, the expenditure will not be given the right direction, and so accomplish a part only of what might have been accomplished, or, on the other hand, will include much that was not essential and so not return interest on the capital invested.

In attempting to improve an old line, as compared with a line which is still on paper only, we are at once better and worse off. On the one hand, we have a positive knowledge of its earnings, expenses, and traffic, and far more definite premises for estimating the possibility and value of any change therein. We know how much locomotives do and can do on the line, how much they are now assisted by momentum in passing over their heavy grades, and where they are most taxed. Above all, perhaps, we have time fully to consider and investigate all the conditions.

Also we have the disadvantage that any changes of line or grade, or of positions of stations or watertanks, etc, etc., involve the throwing away of a certain amount of work already done, instead of the mere addition of a new red line to the maps and a new line of stakes on the ground. For this reason, a change which might have been in every way expedient in the beginning may not be expedient when loaded with the cost of two lines instead of one. We have, moreover, the disadvantage that the value of property and number of buildings are likely to have greatly increased, often to a prohibitory limit, especially near stations and large towns, where changes are most likely to prove expedient. Moreover, in cases of considerable changes, involving the abandonment of certain sections of line or even the moving of minor stations or sidings, legal difficulties may arise, with expenses of unknown magnitude resulting, perhaps, from the mere whim of a jury, and requiring the maintenance and operation at heavy cost of work intended to be abandoned. It has been successfully disputed in some instances, at least for a time, whether a corporation has the right in law to abandon sections of unprofitable lines to the detriment of vested interests without payment of heavy damages as compensation for contingent as well as actual injury.

The disadvantage of having to build a line twice over is one which is likely to affect the imagination far more than its real importance warrants. The constant loss from operating a bad line, on the other hand, being so gradual and continuous that it does not affect the imagination at all, the two causes may unite to indispose responsible officers to think of entering upon a policy in which the outlay is certain and seems larger than it is, while the gain is problematical, and even its possibility does not force itself upon the attention.

The defects which are most conspicuous in old lines which it is desired to improve are, in general, these:

1) The passing by of large towns or other sources of traffic which should have been approached more nearly. This effect, although a great one in the laying out of old lines, is ordinarily not one for which alone it is expedient to change the main line, but it is often an element in considering changes which are desirable for other reasons.

2) Excessive curvature; a defect which forces itself with quite sufficient force, as a rule, upon the attention of all concerned, so that there is some danger that expenditures may be incurred in efforts to remedy this evil which might better have been given some other direction.

3) Improvements in gradients, which are generally at once the cheapest and the most important to effect, and to which this chapter will hereafter be devoted.

The defects in gradients, of a remediable character, which are most likely to exist in old lines, are as follows:

1) Stations on heavy grades, including as heavy grades not only those which appear heavy on the profile, but those which are sufficient to prevent starting a full train, although easily enough passed over by trains under normal headway,

2) Grade-crossings of other railroads, which have often been added in great number since the original opening of the line and seriously modified the handling of trains,

3) Needless undulations of grade, avoidable by slight detours, and originally introduced only because the importance of low grades in comparison with a short line or cheap construction was underestimated,

4) Failure to use pushers, or assistant engines: in some cases from mere oversight, but more generally because the line is ill-suited for their use without modifications elsewhere.

On very many lines it has happened that there was some one short stretch on a division where a 50 or 60 ft. per mile grade was unavoidable. Grades approaching this limit were then used on other parts of the line which were easily avoidable, and can easily be taken out, from an idea (correct enough if the use of pushers is not considered) that they were of no importance if not exceeding the maximum. Consequently, when the line was opened, trains had to be quite short. Stations were laid out or have been added from time to time, without reference to the use of any other than the short trains then handled, and new roads have from time to time put in level-crossings, at which all trains were compelled to stop, with similar indifference to consequences, provided the new stop did not require a still shorter train than was then handled.

Thus it may have come about, in the course of years, that there will be a dozen or twenty points on the division where the demand upon the power of the locomotive is almost as great as, and frequently greater than, the resistance on the maximum grade, so that no advantage, or very little advantage, would be gained by the use of pushers anywhere, and the character of the line seems fixed, without entire reconstruction. Yet the whole may be often remedied by some among the following simple ways, at very moderate total cost:

1) The point or points offering most original difficulties and having, probably, the heaviest work and grades (say 60 ft.) may be in some cases

avoided altogether by a detour of a few miles, but in general can more advantageously be operated as it stands with a pusher, thus about doubling the possible trains over it,

2) The points of next heaviest grades - there may be six or eight of them, having grades of 30, 40, and 50 to 60 feet per mile - will in some instances be so short that they are now, or can well be, operated as momentum grades, with or without some slight modification. In some cases the regrading of considerable sections will be necessary, enabling the line perhaps to strike some new town by a detour, but endangering legal complications for damages unless both lines are maintained,

3) The disadvantageous effects of level-crossings may now, happily, be immediately removed in all cases by taking advantage of the laws already existing in some States, and to be easily obtained by effort when they do not exist, permitting such crossings to be operated by interlocking signals without requi-ring trains to stop at them regularly. It is now universally admitted by intelligent and well-informed men, that this is a much safer and cheaper safeguard than the stopping of trains,

4) The unfavorable gradients at stations - very often the chief evil to be cured, although none but the trainmen may fully realize the fact - can be remedied by one or the other of numerous ways, as follows:

(a) By moving the station or the freight tracks only a little ahead or back, so as to reach a more favorable point; if necessary, at important stations, by completely separating the freight and passenger yard and station, and incurring some extra expense for extra operators, switchmen,etc.

(b) By modifying the gradients of the station, or of one or two tracks thereat in the manner indicated in Fig.21, viz. raising the track a, at the lower end of the yard, so as to give a lower grade for starting trains, at the expense of a somewhat higher grade for stopping them, the latter having no other disadvantageous effect than to check the speed of a passing train, acting in place of a brake, to some extent, if the train is to stop.

FIG. 21

(c) By stationing a switchman to open certain switches, and thus saving the necessity of a train stopping at an unfavorable point to open or shut them. On large roads and at large stations this is not a difficulty, but at other points it is one which must be fully borne in mind,

(d) By breaking through, if necessary, general rules as to which trains shall take the side track, and even (in effect if not in form) which trains shall have the right of way. The latter, of course, cannot safely be done in form, but the desired end can be accomplished by taking care in despatching, to have the lightly loaded trains, or those which the grades favor, held for those which cannot well stop at certain stations or only with difficulty. A general rule on this subject is commonly established and put in force over all divisions of large roads - as for instance that east-bound trains have right of way over west-bound, which latter, consequently, are by custom of the despatchers commonly held so as to favor the east-bound trains. But while such a rule may work well enough on most divisions, it may work very unfavorably in others,

(e) At large stations, where there is most likely to be difficulty or great expense in adopting any of the preceding methods a switch-engine which it is found necessary to keep at the stations, but which is not kept very busy, may be utilized to help trains through the yard, and perhaps also over some unfavorable grade-crossing, which is particularly likely to come near to such a station. If the traffic of the line be very heavy this may be possible; but in that case, as a last resort, an engine may be stationed at the yard for the sole purpose of helping trains through it. By modifying the position of the telegraph office it may in general be arranged that the use of such an engine shall cause no extra stoppage of the train.

The best method of determining how much can be effected in these various ways is by observations of the variations of velocity in the handling of heavy trains on the present line in a manner shortly to be described. In this way we eliminate the necessity of considering and allowing for a long list of doubtful elements - which throw a haze of uncertainty over any computation in which they must be separately estimated or guessed at - by simply determining by direct observation the resultant, so to speak, or net effect of them all. For lack of definite knowledge on a number of variable elements, it is difficult, if not impossible, either to compute or to observe separately either the power of the engine or the whole resistance of the train, but we can determine, very accurately and simply, the relation which the one bears to the other - which is all that really concerns us - in this way:

I) When the engine at any given point on the open road loses speed, it is proof that working with the given steam-pressure and point of cut-off it is overloaded, and the amount of velocity lost can be made a measure of how much it is overloaded,

II) Conversely, if the engine gain speed at any point on the open road, under given conditions of steam-pressure and cut-off, it is a proof that it is underloaded, and the observed variations of velocity can be made accurately to indicate how much,

III) If an engine acquires speed in starting very quickly, under given conditions, without slipping the wheels or using sand, etc., or, on the contrary,

IV) If the engine start very slowly, or not at all, without slipping the wheels or using sand, or both - the observed facts may be made a measure for accurately determining what train it could start under similar conditions with fair working efficiency.

By velocity observations of the nature above indicated under varying conditions of wind, weather, temperature, long and short trains, loaded and empty cars, etc. etc. (all of which can be observed on trains by simply waiting for suitable opportunities without affecting or interfering with normal operating practices), we have a positive basis for determining from what is done under those conditions whether or not the comparative ratio of power to resistance on various parts of the line is seriously imperfect.

In other words, we can, by the simple observations suggested and to be described, construct a virtual profile of the road under all extremes of external conditions. We can then compare these virtual profiles and determine whether or not a given set of improvements which produce a desired uniformity of resistance under one set of conditions, as fair summer weather and heavy-loaded trains, will have as great comparative value in stormy winter weather with long trains of empty cars.

Positive determinations of any one of the following doubtful elements we save the need of altogether:

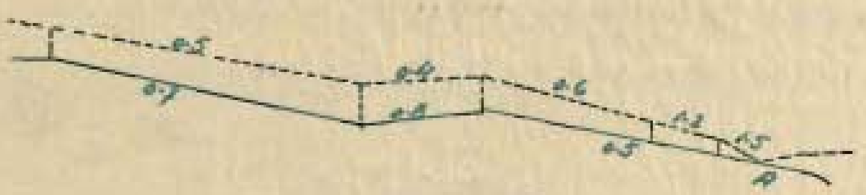
As respects the engine	The ratio and amount of adhesion The cylinder-power The steam-power The head resistance The rolling-friction and friction of machinery The gain from using sand
As respects the cars	The rolling-friction The wind resistance The effect of number and load of cars
As respects the train as a whole	The effect of temperature, state of rail The extent to which momentum may be relied upon to help trains over short heavy grades.

Construction of the virtual profile

Taking an actual profile (which need not necessarily cover the whole line, but may show only the important points; a common profile to working scales is the best), lay off at each point where time records have been taken the vertical height in feet corresponding to the velocity which the train had at that point. By an assumption which is practically correct, the average speed which a train has between any two stations is its actual speed at a point midway between them. The vertical heights should therefore be laid off at corresponding points on the profile.

In this way we obtain our virtual profile, parts of which may be something like the dotted line on the following Fig.22, the solid line being the actual profile

FIG.22



This virtual profile, as we have seen, is that which alone needs to be considered. It presents a line over which, if it were actually constructed, a locomotive, exerting at every point the same energy and overcoming the same frictional resistances, would move at every point without either gaining or losing speed. On this profile what appears to be and what is coincide. If the virtual profile shows a low enough rate of grade we need not be disturbed if the actual profile below it shows a considerably higher grade. On the other hand, if the virtual profile shows a short heavy grade in pulling out from a station, which cannot be reduced by taking more time in starting trains, its disadvantage is not at all less because it is short or because the actual grade below it is almost a level.

The virtual profile will differ according to the direction the train is running, as well as more or less with each record taken; but from all these notes together a safe average is supposed to have been determined at each point.

Studying how to reduce this virtual profile, we recognize three ways:

First (and simplest), To vary the velocity by increasing it in the hollow of grades and decreasing it on the summits and by eliminating or taking longer time for stops. By carrying this process far enough, we may reduce the virtual profile of an undulating line having very heavy grades to a level, as we have seen; but, practically, only minor variations of this kind are admissible,

Secondly (and next simplest), by using pushers,

Thirdly, by reconstruction or amendment of the actual profile.

Let us suppose, as examples are most readily followed, that these observations have been taken and the virtual profiles made over a given division with the results at various points outlined on the Fig.23.

A long hard pull on a 1.2 per cent grade (63.36 feet per mile) shows that the given engines can handle 25 cars, more or less, on this grade with great ease, except in very unfavorable weather. Under fairly favorable conditions the velocity gained without overtaxing the boiler capacity is such as to indicate a virtual maximum grade of 1.4 per cent, or even more.

The same is true at a number of minor points on the same division.

In pulling out at stations, by comparison of many observations, it is found under average conditions that the virtual grade was 1.3 to 1.5 without using sand (being somewhat lower because of the greater journal-friction, and lower because the full adhesion was more nearly used and there was less air and other velocity resistance), while when sand was used the virtual grade was raised to 1.6 or 1.8. On the other hand, with very unfavorable weather and a bad rail, the virtual profile in starting is 1.2 to 1.4, even with use of sand.

Under these conditions we have, in the first place, an indication that the trains now handled on the road as it stands are somewhat smaller than they might be - an indication which is alone worth the trouble of an investigation of this kind, and can in no other way be so accurately determined. Passing that question, however, as not now under consideration, we have a very positive indication that we shall be safe in assuming that by using a pusher of equal power over the worst grade, we shall in effect reduce it to the equivalent for a single engine of a pusher grade of 1.2 per cent. If we find it easy of accomplishment, we may consider reducing it still lower and using a heavier pusher engine, but such a course is to be adopted with caution.

The actual grade at stations on this grade should not be more than 0.5 for at least 700 ft., and 1.0 for 1000 ft. beyond, but by use of sand may be somewhat higher for short distances.

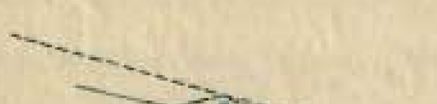
FIG. 23

Over the remainder of the division we are likely, at various points, to have cases like the following:

A station grade at A (Fig.23), on an actual grade of 0.6, is operated very easily now, the train quickly getting under way even without the use of sand. By taking more time for starting heavy trains (say attaining full working speed at B) the virtual grade might be reduced, perhaps, to .75, but it is necessary to reduce it to 0.5 at least, and if possible to 0.4, the actual grade needing to be considerably less.

The neatest and most effectual method is to remove the station at once from A to B, this alone having the effect of favorably modifying the virtual profile far more than was desired, giving that shown in Fig.24.

FIG. 24



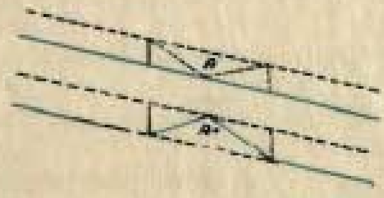
If this be impossible, the next best method is to take out the bad gradient in the virtual profile by raising the grade at A on the actual profile to

A', giving it the form shown in Fig.25. Changes of this kind are apt to be expensive because of their locality; but, on the other hand, they are inexpensive in that they are seldom very long. The effect is to substitute (in the lower half of the diagram) a broken actual but good virtual profile, in place of a good actual but bad virtual profile, as in the upper half of Fig.25.

A modification of the same case may be as follows: a station originally well situated, as S, (Fig.26) but which has been complicated by subsequent additions of gra de-crossings for other lines C and C', at which all trains have to stop and start again on a grade.

The first and best remedy for this evil is the use of interlocking signals, saving the necessity of a stop except to let another train pass; but as that is a contingency which may happen not infrequently, it can never be a perfect, nor in some cases sufficient, remedy.

FIG. 25

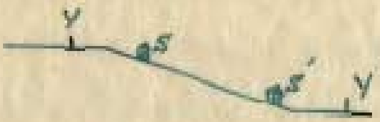


The evil may also, in cases, be remedied by raising the grade of the track approaching the crossing as outlined at C and C', provided the virtual grade of the approach be not increased thereby to an inadmissible rate. The only remaining course is either to use a yard engine as a helper over the crossings or boldly to lower the grade by passing under each road, and grading a new road-bed or lowering the existing one, for which room may be so scant as to require retaining-walls. This will make the improvement a costly one, and yet the cost will probably be small in proportion to the gain, unless it is only one among many costly improvements required for the desired end.

At large towns it is a very common thing to find the station located at some point S or S', Fig.27, which was originally fixed more with reference to the convenience of the town than to the grades. This is of course the proper thing to do, and a decrease of station facilities, or a change causing inconvenience to the patrons of the line, will in general be inexpedient. Such large stations, moreover, are generally well provided with side tracks, so that the result is that they are largely used by train-dispatchers as passing points.

FIG. 26

FIG. 27



The proper remedy in such cases is to establish sidings, Y or Y', to serve as passing points for through trains only, with a separate telegraph office, leaving the local facilities undisturbed. This requires the services of two operators to do the work of one, and perhaps one or two other otherwise needless employees, but the wages of one train crew for a single trip, it should be remembered, will pay the wages of a good operator for a week.

The case sketched in Fig.27, moreover, is one of those where the whole difficulty in handling heavier trains may be made to vanish by a modification of the system of dispatching, to the effect that only trains going down grade, or say east, shall be held at this station and compelled to take a side track (except, of course, in emergencies), especially if there be another regular station near to it, as Y or Y', which may be used as a passing point, by holding one or the other train, in case it is impossible for the eastward train to reach S orS' first. It is not essential, although it is convenient, that a dispatcher should feel at liberty to hold any train, bound either way, at any station, in the regular routine of business, provided that to do so interferes with a material addition to the train-load. It is the rule and not the exception, however, that he can and does do so.

The decision as to what course to adopt for modifications of gradients on the open road is a much simpler matter than at stations. The vital point to be determined in the beginning, before studying the details of the various difficult points at all, is what rate of speed is practicable and allowable at the foot of the grade, which largely depends on the alignment. The modern tendency is very decidedly to permit of higher speed in handling freight trains, and it is essential to do so at points to handle the maximum train on all undulating gradients. It has been tolerably well determined before that higher speeds than 15 miles per hour are more economical for freight trains; and the not uncommon feeling that any speed of over 15 or 20 miles per hour verges on the dangerous is in part a relic of the old days of iron rails, poor ballast and road-bed, and less solidly constructed rolling-stock.

Therefore, when required for reducing virtual gradients by taking a "run at them" as part of a general system of improvements, a speed of 30 miles per hour, with fair alignment; and with a tangent in the hollow of the gradients this limit may in general be safely increased to 35 miles, if that speed seems essential. These speeds and even higher ones are now frequently used in handling freight trains on many lines.

By attacking the work of improving old lines in the method here outlined, halving the more formidable and inevitable grades at once by using a pusher on them, without spending money on them, and spending all our money on what were before the very easy grades, and hence are usually in light work, the average train-load may be doubled at small cost on thousands of miles in this country; whereas by merely attacking the heaviest grades which show on the profile with force and arms, so to speak, a great deal of money must be spent, and there will be little to show for it.

CHAPTER XV

Grade-crossings and Interlocking

As a consequence, many important lines have little or no assurance that crossings may not be demanded of them sooner or later on any single mile of their track, and it becomes of great importance to determine how they should oppose such crossings, what expense they may and should incur to avoid them, and what can be done to reduce their disadvantages to a minimum when unavoidable.

In England there are practically no grade crossings of railways, and this apparatus is used chiefly for yards and junctions. In America there are a great many grade-crossings, even on important lines; and the clumsy and costly precaution of a full stop of every train at every crossing was still the rule, although it can hardly be that such an absurd relic of barbarism would linger much longer, when there was a considerable and increasing number of grade-crossings operated without a stop by the aid of interlocking apparatus, and always with perfect safety and success.

In the part, the slow progress in this matter is easily explained. The great loss and delay from grade-crossing stops goes on quietly, without interfering much with the routine of operation.

Nevertheless, from an economical point of view, abolishing the stop at grade-crossings is by far the most important, especially when, as is so frequently the case, they reduce the number of cars hauled below what it otherwise would be.

With the lightest ordinary traffic, the lowest reasonable estimated cost of stop, and the highest probable rate of interest, the sum saved annually is far more than enough to cover the additional expense of thoroughly protecting a grade-crossing so that no stop need be made, without considering the greater safety and convenience. At more important crossings it would be hard to find a clearer case of an expedient improvement, even if the stops do not cut down the length of the train.

If the length of train is cut down, so as to take, say, 21 instead of 20 trains per day to handle the traffic, the very lowest cost for which the extra train can be run is 35 to 40 cents per train-mile.

A fact which explains rather than excuses the prevailing negligence in this matter is this, - that the protection of grade-crossings requires the joint action of two roads, usually under different and often under antagonistic management, and it requires no little negotiation, and a conciliatory spirit on both sides, to arrange the details of the distribution of the expense.

It can hardly be doubted that this difficulty is a serious one, and it is largely the fault of the laws which authorize the use of interlocking as a substitute for stops.

To require that grade-crossings should never be permitted would be going too far, especially now that interlocking apparatus has been invented and perfected, but the unrestricted freedom with which, in most of the States, grade-crossings can be forced over any line at almost any point, regardless of the injury inflicted, is an unfortunate and shameful state of things, which pressingly requires correction, and which perhaps might readily be corrected if the older and more important railways would make a united effort to secure reasonable and proper restrictions. Unfortunately they overreach themselves by asking far too much.

The solution of the whole matter seems comparatively simply. All railways alike are supposed to be of pressing necessity to a certain number of people - many or few, as the case may be; and the necessities of even a very few are given greater weight than a loss and inconvenience which is comparatively trifling to each individual affected, and can only become very large when distributed among a large number of people.

1) Every railway hereafter attempting to cross another at grade shall be obliged to erect and pay for a system of interlocking signals, to be thereafter maintained at the joint expense of the two roads, unless it shall appear that less than twenty trains per day pass the crossing,

2) Any railway may at any time erect interlocking apparatus at any grade-crossing, with certain provisions for exceptional cases; and also provided -

3) Either party wishing to avoid a grade-crossing should be at liberty to locate an over-or under-crossing on unobjectionable gradients, and to demand the appointment of arbitrators in the usual manner. It should be the duty of these arbitrators, first, to determine that the grades and alignment of the new line are of a suitable character, secondly, to determine the excess in cost, of the overcrossing over the grade-crossing, and, thirdly, to assess this difference in cost upon the two lines in proportion to the benefit to each of avoiding a grade-crossing.

These three provisions seem calculated to accomplish what every good law ought to accomplish. They would make it for the interest of both parties to take that course which would be best for their joint interest, if they were one corporation. Thus, supposing a new road which will run say five trains a day wishes to cross a trunk line running 50 trains a day. The actual loss to the community of a grade-crossing at such a place is the cost of stopping 55 trains a day, and no one has a right to enforce such a loss upon others to save an investment of a few thousand dollars. On the other hand, if the new project wanted to cross another minor line like itself, running, say, five trains a day, neither road would be likely to move for an over-crossing, nor perhaps even for interlocking signals; nor is it for the interest of the community, considered as a whole, that they should do so. It is not true at all that every element of danger must be wholly eliminated before any saving of expense, however great, is permissible, but that methods which are at once more dangerous and more costly should have continued in such wide and all but universal use so long will seem in later years a strange comment on our civilization.