then many roads estimate so many cars as a train load irrespective of the load on the car, and the adoption of a tonnage system for making up train loads will, in many cases, effect great economy.

It is noticeable that, on heavy grades, the level tangent resistance forms a very small proportion of the total resistance, and also that, for any given increment of grade, the increase per cent. of engine mileage is much less as the grades become heavier.

Decreased hauling capacity, on heavy grades, may be met in two ways, either by increased weight of engines, especially the weight on the drivers, as is evident from Table IX., or by increasing the number of trains (*i.e.*) the engine mileage.

The former is, of course, the cheaper method, but as the changes in grades that an engineer is called on to discuss are usually relatively small, it is only fair to suppose that the economy of heavy engines will have been realized in both cases; but supposing it possible to increase the weight of engines for heavier grades, only very few of the expenses of operating are increased. Wellington estimates that track maintenance, renewals and engine repairs are increased 50 per cent. as fast as the weight of the engine increases; fuel 25 per cent. and other items practically unaffected. Altogether, the operating expenses will only increase 14 per cent. as fast as the increase in weight of engines.

On the other hand, the usual necessary course on heavier grades will be to run more trains of less tonnage, with the same weight of engine, for a given traffic. This is a more expensive matter.

TABLE X.

INCREASE OF OPERATING EXPENSES WITH INCREASED ENGINE MILEAGE.

Item.	Cost of Item.	Per cent. increase.	Extra cost
Fuel, oil, and waste..................	8.8 %	67 %	5 9 %
Engine repairs	5.6 "	75 "	4.2 "
Switching engines....................	5.2 "	0 "	.0 "
Train wages	15 4 "	100 "	15.4 "
Car maintenance	12.0 "	− 10 "	− 1 2 "
Track maintenance, etc	17.5 "	100 "	17.5 "
Bridges and buildings	5.5 "	0 "	0.0 "
Station and general	30.0 "	20 "	6 0 "
Interest on extra engines	....	..	1.7 "
	100 %		49 5 %

It will be seen that, say, 50 per cent. of the operating expenses increase with an engine mileage increase, as compared with 14 per cent. in the first case. This is why the weight on drivers is being continually increased, and the strength of the track to carry it, on all roads having much traffic to handle, as being the cheaper expedient.

We are now prepared to estimate the cost of increasing the ruling gradient on an engine division (100 to 125 miles).

Taking a train mile to cost 90 cents, we have 90c. × 365 × 2 = $657, as the cost of hauling a daily train (both ways) per mile, per year. If we take this *yearly train unit*, multiply it by the number of miles in a given engine division, by the increase in the number of daily trains necessitated by the heavier grades, and then by 50 per cent. (see Table X), we will have the amount which it will probably cost per year more to operate on the heavier grades than the lighter ones. If we capitalize this sum we get the amount which, for a given traffic, it would be wise to expend to construct a road with the lighter ruling grades rather than the heavier ones. (*e.g.*) To avoid changing our ruling grades from 1.0 per cent. to 1.5 per cent. on a hundred mile division, we would be justified in expending anything less than

$$\left(\frac{1000}{504}-\frac{1000}{711}\right)\times \$657\times 100\times 50\%\times \frac{100}{5} = \$328,500$$

for every 1,000 tons of gross freight per day, taking a seventy five ton consolidation engine as the basis of comparison, and, roughly, two trains per day in one case and one train one day and two trains next day, in the other case, or one-half train per day difference. Now this is a very modest traffic, and yet we could afford to expend $3,285 per mile more in one case than the other, and it is really very much more than it appears, for two reasons:

(1) Because ruling grades in most cases will probably not extend over more than one half of the road as a maximum, and we can therefore spend twice as much per mile on them, or $6,570 per mile as a minimum, on the portions to be improved.

(2) Because all this money can be used below the ballast since track, equipment, stations, etc., in fact, all other items, remain unchanged, now to show how moderate a proportion the cost of substructure is of the cost of the whole road, the following table is given:

TABLE XI.

COST OF FOUR TRACKS OF N Y.C. AND H.R. RAILWAY PER MILE.

Grading and masonry.....................	$22,000	=	18.9	per cent.
Bridges	3,030	"	2.6	"
Superstructure..........................	32,500	"	27 9	"
Stations, etc	15,400	"	13 3	"
Land and damages	15,740	"	13.6	"
Engines and cars	24,077	"	20.7	"
Engineering and incidentals..............	3,453	"	3.0	"
	$116,200	"	100	"

This is an extreme instance, as grading was light and equipment expensive; the items affected (1 and 2) are only 21½ per cent. of the total, and probably 25 to 40 per cent. will give a good average for ordinary single track roads. Each country traversed is suited to certain maximum gradients, and an endeavor to modify them extensively will bring very heavy additional expenses, but within narrow limits, such as a change of ruling grades by as much as $\frac{2}{10}$ or $\frac{3}{10}$ per cent., the advantages of a liberal expenditure of money to obtain the lesser grade are often overlooked and the "penny wise" maxim adopted. Every engineer who has the decision of the ruling grade should study such figures carefully, and by as extensive surveys as possible determine what is the least ruling grade that he can get at a cost which will be justified by present or expected traffic, always, of course, considering how much money can be got at all, for no expenditure can be justified that will in any way endanger the successful completion of the road; he must consider each item of expenditure or economy, *per se*, whether it is wise or not, remembering always that it is the *difference* of gross receipts, working expenses and fixed charges that is to be thought of in determining the best general route.

Note, however, that these calculations and estimates do not hold strictly true for roads of very light traffic, because some trains must be run in any case to accommodate traffic at certain intervals, and if they are not fully loaded, then an increase of grade will not have any effect until it causes an increase in the number of trains, as a change in the rate of grade does not usually mean any increase in the total rise or fall.

In comparing two routes for costs of operation the best method is to assemble the curves and grades of different classes and take their differences, pro or con, also the difference in the number of trains per day necessary to handle the probable traffic. These differences multiplied by their proper multipliers will give a comparison of how much more valuable one route will be than the other for a given traffic, and will determine consequently how much more can be justifiably spent to construct one route rather