speed of trains when the sharpness of the curves is over a certain amount varying with different conditions. On competing lines, however, this may be a serious matter, not only on account of time lost, but also due to the apprehension of danger, and because the curvature may produce rough and unpleasant riding. These objections to curvature may be almost entirely eliminated as regards the number of trains required to handle the traffic as the only feature which might control this is the possible increase of a ruling grade by an uncompensated curve, and this may readily be eliminated by compensating curves on ruling grades. On minor grades uncompensated curvature has but little effect, as it merely increases the rate of grade, and unless the original grade plus the increase in grade due to curvature does not exceed the ruling grade it will not limit the tonnage of trains in any way. If, however, the combined effect would be to make the resistance more than that due to ruling grades, then trains loaded up to the maximum for those grades would be liable to stall on the curve.

Grades on the lower side of a stopping place need not be compensated for curvature, because the resistance due to the curve will reduce the work required in braking the trains. When a curve occurs above a stopping place it should be compensated in an even greater degree than ordinarily.

Curves should evidently be compensated an amount equal to that grade which would produce the same resistance as the curve. The resistance due to curvature being a variable quantity depending on the speed of trains, compensation for fast passenger trains may be made quite low, but for slow and heavy freight trains, which are the most important, it must be gradually increased. Webb advises 0.04% to 0.05% per degree for ordinary degrees of curvature. The maximum degree of curvature permissible on any road is a matter on which opinions differ considerably. Some roads limit their engineers to a maximum curvature of 6 degrees, others leave this to the judgment of the engineer. There is no serious objection up to a certain limit to a few sharp curves where the amount saved may be sufficient to justify their introduction. One limiting feature of the maximum curvature is the ruling grade. For instance, where the ruling grade on a line is 0.4% and the rate of compensation has been fixed at 0.4% per degree of curve, it is obvious that a ten-degree curve is the maximum permissible, as this degree has theoretically the same resistance as a .4% grade, and if the 10-degree curve was located on a ruling grade to be correctly compensated the grade would have to be eliminated entirely.

Curvature has a very marked effect on the maintenance and operating expenses of a line. Rails on curves wear much more rapidly than those on tangents; it has been computed that the wear on a rail on a 10-degree curve is 226% of the rail wear on a tangent, under similar conditions of traffic, and that it is approximately proportional to the degree of curve. Ties are also adversely affected by curvature owing to increased rail cutting, and they need more frequent respiking. Wellington states that the deterioration of ties is also proportional to the degree of curve. That part of the roadbed under sharp curves has to be more frequently reballasted, especially when the superelevation is high. The expense of repairs and renewals becomes greater owing to the harder wear on locomotive tires and wheels, thus increasing shop expenses.

The increase of tractive resistance due to curvature naturally tends to increase the fuel consumption of locomotives. Webb charges 44% of the average cost per train mile for an addition of 528 degrees of central angle into a mile of track. In some mountainous regions where a number of sharp curves are unavoidable operating expenses may be sometimes increased by locating these curves in deep cuts, thus necessitating the use of watchmen to warn trains of obstructions due to snow slides, etc., or, as an alternative, the speed of trains must be reduced as they pass these places.

The following table (abbreviated from Webb) gives some idea of the items affected by curvature, being based on the addition of 528 degrees of central angle into a mile of track.

TABLE VII.

Item.	Normal average.	Cost per mile per cent.
Maintenance of way	20.09	5.93
Maintenance of equipment	22.74	28.70
Traffic expenses	3.08	0.00
Conducting transportation	50.44	5.02
General expenses	3.65	0.00
	100.00	39.65

It will be seen from this table that an addition of 528 degrees of central angle into a mile of track increases the expenses per train mile by 39.65% of the average cost per train mile. Assuming that the increased expense is directly proportional to the amount of curvature, which, in the majority of cases, is very nearly true, then one degree of additional central angle per mile would increase the train expenses by .075%. If, again, we assume that the average cost per train mile to be $1, the cost per annum per daily train would be 27.375c. This result is, of course, entirely approximate but will give a better idea of the value of a proposed change than any unbased estimate, and will show whether the improvement will be justified, due to possible increase in business.

Grades.—The effect of grades on train expenses is of the greatest importance. Tonnage of trains is fixed by the ruling grade on the section of line under consideration, a heavy ruling grade necessitates shorter trains and consequently more of them. Gross receipts from traffic is a fixed quantity regardless of the number of trains necessary to handle it, while the cost of handling the traffic will be nearly proportional to the number of trains. A reduction of ruling grade, on the other hand, reducing as it does the number of trains and therefore the operating expenses, will justify a large expenditure to accomplish this result. Where the line runs through comparatively level stretches of country with light grades, very little can be done to favorably affect the grade, but humps and sags in otherwise uniform grades may be eliminated. No figures on the resistance to movement of a train on straight level track can be considered accurate for all cases, as they depend on speed, length of trains, character of cars, and condition of weather and roadbed, but 10 lb. per ton is frequently taken for average conditions and velocities. This is equivalent to the retarding effect of a 0.5% grade.

The rate of ruling grades are necessarily limited by the general character of the road. A road designed to meet the requirements of light traffic would naturally not be justified in a large expenditure to reduce the rate of ruling grade, whereas on a road built for heavy traffic this would be of prime importance. Methods of operating the trains will, to a large extent, minimize the effect of ruling grades, the road being divided into divisions, at the termini of which sorting yards may be located, and the trains