TRAIN RESISTANCE.*

By W. F. Kiesel, Jr.

The bulletin on train resistance prepared by Prof. E. C. Schmidt and recently issued by the University of Illinois, describing tests with freight cars, adds much to assist in finally determining a general formula on train resistance of value to engineers, even though the author of the work has not attempted to develop a formula generally applicable to all cars. A study of this subject for the past ten years, or more, has permitted me to gradually develop a formula, the results of which agree very closely with those of the careful tests described by Prof. Schmidt.

In the April, 1897, number of the Revue Generale des Chemins de Fer, M. Barbier, of the Chemin de fer nu Nord, presented formulae for train resistance, which, in construction, have been followed by nearly all other investigators. In the Railroad Gazette of May 21, 1897, M. Barbier's formulae were discussed, compared with others, and transformed into formulae with English measurements, as follows:

For rigid axles: $R = 3.2 + 2.5V \frac{(V + 30.8)}{1000}$

For truck axles: $R = 3.2 + 2.5V \frac{(V + 6.08)}{1000}$

Attention is directed to the fact that the composition of the train, the number of cars, and the total train weight have not been considered. In June, 1899, the Pennsylvania Railroad test department made some careful tests with empty and loaded freight cars, whose weights varied from 13 tons to 75 tons. These cars were in good condition and the most careful records were taken. The results clearly demonstrated that the resistance per ton at very slow speeds decreased as the weight per car increased. The following formula expresses the results very closely:

$$R = \frac{80}{W} + 1.1$$

R = resistance in pounds per ton, and W = car weight in tons.

Comparison with tests made since indicate that the average freight cars are not in as good condition as those used in the test referred to, and that some allowance should also be made for variations in weather. Changing coefficients to conform, the formula reads:

$$R = \frac{100}{W} + 1.5 = \text{Resistance per ton.}$$

or $R = 100 + 1.5W = \text{Resistance per car.}$

Using M. Barbier's general formula

$$R = C + C_1V + C_2V^2$$

or as re-arranged by the Railroad Gazette in 1897,

$$R = C + C_2V\ (V + \frac{C_1}{C_2})$$

where

V = speed in miles per hour,

and substituting the value $\frac{100}{W} + 1.5$ for C,

making $C_3 \frac{C_1}{C_2}$ and $C_4 \frac{1}{C_2}$ the formula becomes:

$$R = \frac{100}{W} + 1\tfrac{1}{2} + \frac{V\ (V + C_3)}{C_4}$$

The values of C_3 and C_4 in the third term represent air resistance and all other resistances depended on speed and had to be empirically determined; they have been gradually modified due to a study of the tests and experiments of the past ten years. For best average results $C_3 = 16$, and $C_4 = 100$. These tests also indicate that the third or average speed term varies as the square root of W, which gives for resistance per car:

$$R = 100 + 1\tfrac{1}{2}\ W + .01\ V\ (V + 16)\ \sqrt{W}$$

The resistance per ton will be this value divided by W, or

$$R = \frac{100}{W} + 1\tfrac{1}{2} + \frac{V\ (V + 16)}{100\ \sqrt{W}}$$

If W_1 is made to represent the total weight of the train back of the tender, and N the number of cars, then:

$$R = 100N + 1\tfrac{1}{2}\ W_1 + .01\ V\ (V + 16)\ \sqrt{W_1N}$$

This formula gives good average results for solid trains, including passenger trains with open platforms. For mixed freight trains having various kinds of cars, which increase the air resistance, the denominator of the speed term should be changed from 100 to 90, or possibly 85.

For vestibuled passenger trains, presenting a rather smooth surface, the air resistance will be less, and the denominator of the speed term may be increased to 110, or, in exceptional cases, to 120. For ready comparison with

Freight Car Resistances in Pounds Per Ton on Level Tangents for Car Weights; in Tons.

Miles Per Hour.	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	6.735	5.710	5.025	4.535	4.166	3.879	3.648	3.460	3.302	3.163	3.054	2.954	2.867	2.790	2.722
10	7.081	6.200	5.308	4.768	4.411	4.110	3.868	3.669	3.502	3.361	3.239	3.134	3.041	2.958	2.885
15	7.540	6.430	5.682	5.143	4.735	4.415	4.158	3.945	3.767	3.615	3.484	3.370	3.270	3.181	3.101
20	8.110	6.940	6.148	5.574	5.138	4.796	4.518	4.289	4.096	3.931	3.789	3.665	3.555	3.457	3.370
25	8.792	7.550	6.705	6.099	5.621	5.250	4.950	4.700	4.490	4.310	4.154	4.017	3.896	3.789	3.692
30	9.586	8.260	7.353	6.661	6.182	5.779	5.452	5.179	4.948	4.750	4.578	4.427	4.293	4.173	4.066
35	10.491	9.070	8.092	7.375	6.847	6.383	6.024	5.725	5.471	5.222	5.062	4.894	4.746	4.613	4.493
40	11.509	9.980	8.923	8.144	7.541	7.061	6.668	6.339	6.059	5.817	5.606	5.420	5.254	5.106	4.972
45	12.638	11.590	9.845	8.998	8.340	7.814	7.382	7.019	6.711	6.438	6.210	6.003	5.819	5.654	5.505
50	13.879	12.100	10.858	9.936	9.222	8.641	8.167	7.768	7.427	7.147	6.873	6.644	6.439	6.256	6.090
55	15.231	13.310	11.963	10.959	10.174	9.543	9.022	8.584	8.208	7.882	7.596	7.209	7.116	6.912	6.727
60	16.696	14.620	13.158	12.038	11.209	10.520	9.959	9.467	9.054	8.694	8.376	8.232	7.848	7.623	7.418
65	18.273	16.030	14.445	13.243	12.324	11.571	10.946	10.405	9.964	9.569	9.222	8.913	8.636	8.388	8.161
70	19.961	17.540	15.824	14.534	13.518	12.696	12.013	11.435	10.938	10.505	10.124	9.784	9.480	9.201	8.957
75	12.761	19.150	17.293	15.896	14.790	13.898	13.152	12.517	11.978	11.504	11.086	10.714	10.380	10.080	9.805
80	23.672	20.860	18.854	17.341	16.142	15.171	14.361	13.916	13.061	12.564	12.108	11.701	11.336	11.007	10.707

*From Railway Age Gazette.