Chicago, Milwaukee & St. Paul Railway Electrification

With Section Opened This Year Total Is 647 Miles, Including Heavy Grades Over Five Mountain Ranges —Types of Locomotives—Reported Operating Results

WITH the opening this year of the 209-mile electrified division of the Chicago, Milwaukee & St. Paul Ry., from Othello to Tacoma, Wash., the total length of electrification on the Milwaukee is 647 miles of main line, or 860 miles of track including passing tracks and sidings—by far the greatest in extent of electrification on any one railroad. The 438 miles between Harlowton, Mont., and Avery, Idaho, were put in electric operation January, 1916. The shorter line is operated as a single division and the longer line constitutes two divisions. Each electric division includes two divisions formerly operated by steam locomotives, as the necessity of cleaning fires of such locomotives limited runs to about 100 miles. The two electrified sections are separated by a stretch of 212 miles which is still operated by steam. This section does not present the severe operating conditions which obtain on the two adjacent sections.

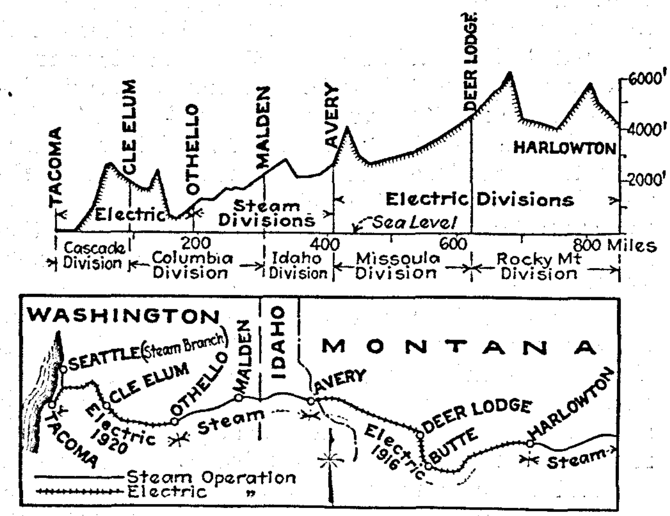


FIG. 1. ELECTRIFIED SECTIONS OF CHICAGO, MILWAUKEE & ST. PAUL RY.; 647 MILES

From Harlowton to Avery three mountain ranges of the continental divide are crossed, with summit elevations of 5,788, 6,322 and 4,150 ft. Heavy grades and a large proportion of curvature are encountered, the maximum grade being 2 per cent for 21 miles and maximum curvature being 10 deg. on the main line. Of 36 tunnels the longest is the 1½-mile St. Paul Pass tunnel through the Bitter Root range. This 440-mile stretch of electrification was described in *Engineering News* of Jan. 7, 1915, p. 22, and July 6, 1916, p. 24, and in *Engineering Record* of Oct. 23, 1915, p. 518.

The newer electrified division extends west from Othello, Wash., to Tacoma, 209 miles, with a 9-mile branch from Black River Junction to Seattle which has not yet been converted to electric traction. This division crosses two summits of the Cascade range at Boylston (El. 2,390 ft.), and in the Snoqualmie tunnel (El. 2,564 ft.), as shown by the profile, Fig. 2. Westward, the maximum grade is 2.2 per cent for 18 miles to the Boylston summit, followed by a descent of 1.6 per cent. Grades to the Snoqualmie summit are relatively easy, 0.4 to 0.7 per cent. On the western slope, however, there is a descending grade of 1.74 per cent for about 20 miles, followed by a ruling grade of 0.8 per cent for 25 miles, the latter bringing the line down to the coastal plain. There is about the same proportion of curvature as on the Rocky Mountain electrification, with the same maximum of 10 deg. for main track curves.

Power Supply and Transmission—Current for the Cascade electrification is purchased from the Intermountain Power Co. and is transmitted from the plants of two supplying companies. A transmission line of 113 miles extends from the Long Lake plant of the Washington Water Power Co. to the railway substation at Taunton, Wash. Two lines extend from the Snoqualmie Falls plant of the Puget Sound Traction, Light & Power Co. to the substation at Cedar Falls and Renton, ten and twenty miles respectively. The second of these lines continues 26 miles to the last substation at Tacoma

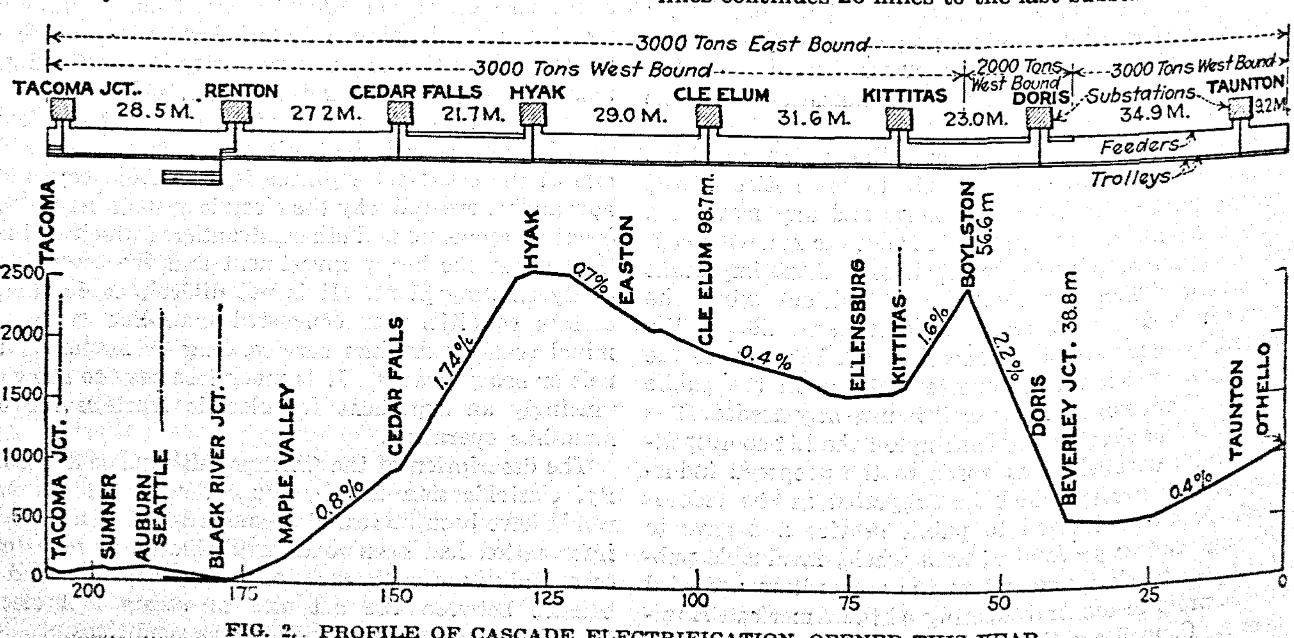


FIG. 2. PROFILE OF CASCADE ELECTRIFICATION OPENED THIS YEAR

Junction. There are eight substations, each with either one or two motor-generator sets of 2,000 kw., and space for an additional set.

Transmission lines from the power plant are carried by steel towers and wood poles. Those along the railway are carried mainly by 50-ft. wood poles with an average spacing of about 300 ft. The trolley line on main track consists of two parallel wires hanging side by side, thus giving greater flexibility and greater area of contact than a single wire. These wires are suspended by hangers from a catenary cable carried by bracket arms on single poles or by span wires between pairs of poles. On tangent line and single track poles are spaced 150 ft. For passing and yard tracks a single trolley wire is used. Current at 100,000 volts on transmission lines is stepped down to 3,000-volt direct current for the trolley wire. For the return circuit the 90-lb. track rails are supplemented by a wire carried on the poles and connected to the rails at intervals of about 8,000 ft. This wire connection serves to compensate for defective or broken rail bonds. Regenerative control or braking is a feature of the electric system, as on the older line, the motors acting as generators when the train is descending grades and delivering current to the trolley line. In this way the speed is controlled by the current returned to the line, the air brake being used mainly to stop the train and as an auxiliary while running. Automatic block signals are installed on both districts.

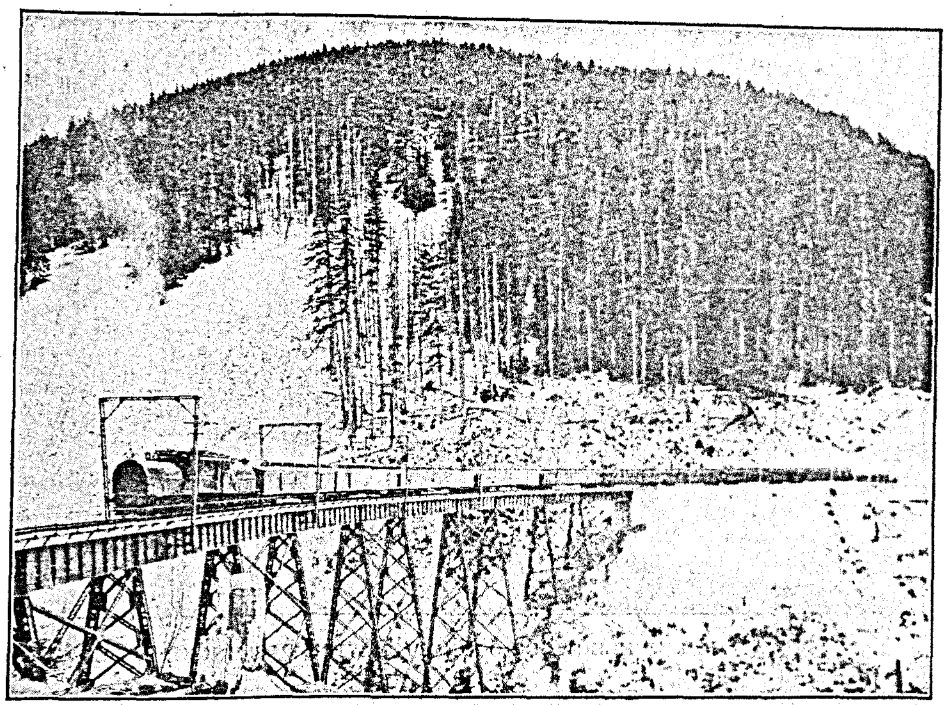


FIG. 3. PASSENGER TRAIN ASCENDING THE WESTERN SLOPE OF THE CASCADE RANGE

Locomotives and Traffic—Electric locomotives of two radically different types are employed, mainly for the reason that after extended investigations it was considered desirable to have service experience with these types under the actual operating conditions of the line. The motive power equipment of the two districts comprises 15 passenger engines, 42 freight engines and four switching engines. On each district the traffic averages two passenger trains and from three to four freight trains in each direction daily.

Freight locomotives are of the 4-8-8-4 type, composed of two connected units. Those used on the new line were formerly passenger engines on the older line, the gear ratio having been changed for freight service. In the original equipment of the older line the passenger engines were similar to the freight engines, except for a lower gear ratio, since it was thought that a suitable type of engine for passenger service should be determined on the basis of actual electric operation, the older passenger locomotives being then converted for freight service. These engines have 52-in. driving wheels with a motor of 375 hp. (continuous rating) geared to each axle. Freight train tonnage varies from 2,500 tons on 2 per cent grades to about 5,000 tons on grades of 0.4 per cent, helpers being employed on continuous grades of over 1 per cent. For passenger service, fifteen new locomotives were built in 1919, five being used on the new line and ten on the older line. They are of two different types, but are all designed to meet the railway company's requirements for hauling a train load of 950 tons (twelve steel cars) at 25 m.p.h. on grades of 2 per cent and 30 to 37.5 m.p.h. on grades of 1 per cent. The maximum speed is 65 m.p.h. on level tangents and the engines have to be sufficiently flexible to pass curves of 16 deg. in yards as well as 10 deg. main-line curves. Current is taken from the trolley line by pantagraph collectors.

On the newer Othello-Tacoma line there are five General Electric passenger locomotives having 24 driving wheels, with a two-wheel truck at each end. The wheels are grouped in four trucks with articulated connections. Each of the end trucks has six wheels, four of which are drivers while the end wheels have lateral play and have no motors. Each of the two inner trucks has eight driving wheels. The two cabs for apparatus and operating crew are integral with the eight-wheel trucks, the front of each cab being supported by rollers on its six-wheel truck. The heater cab in the middle is supported by a three-point suspension from the inside ends of the two main cabs and is carried entirely free of the trucks. Thus the locomotive forms a single and inseparable articulated unit, having both the trucks and the cab articulated. These engines are of the gearless type, with a bi-polar motor of 250 hp. (continuous rating) on each driving axle (see *Engineering News-Record*, Dec. 11, 1919, p. 1034). One of these is shown in Fig. 3.

For the Harlowton-Avery line, there are ten Westinghouse-Baldwin passenger locomotives (Fig. 4) having a 4-6-2-2-6-4 wheel arrangement (with twelve driving wheels), the running gear being composed of two separate 4-6-2 units coupled back to back but not articulated. A single cab is mounted on these two units. Each unit, with its six driving wheels, has six twin motors, each motor frame housing two armatures. The pinions of these two armatures engage a single gear mounted on a quill which surrounds the driving axle, the torque

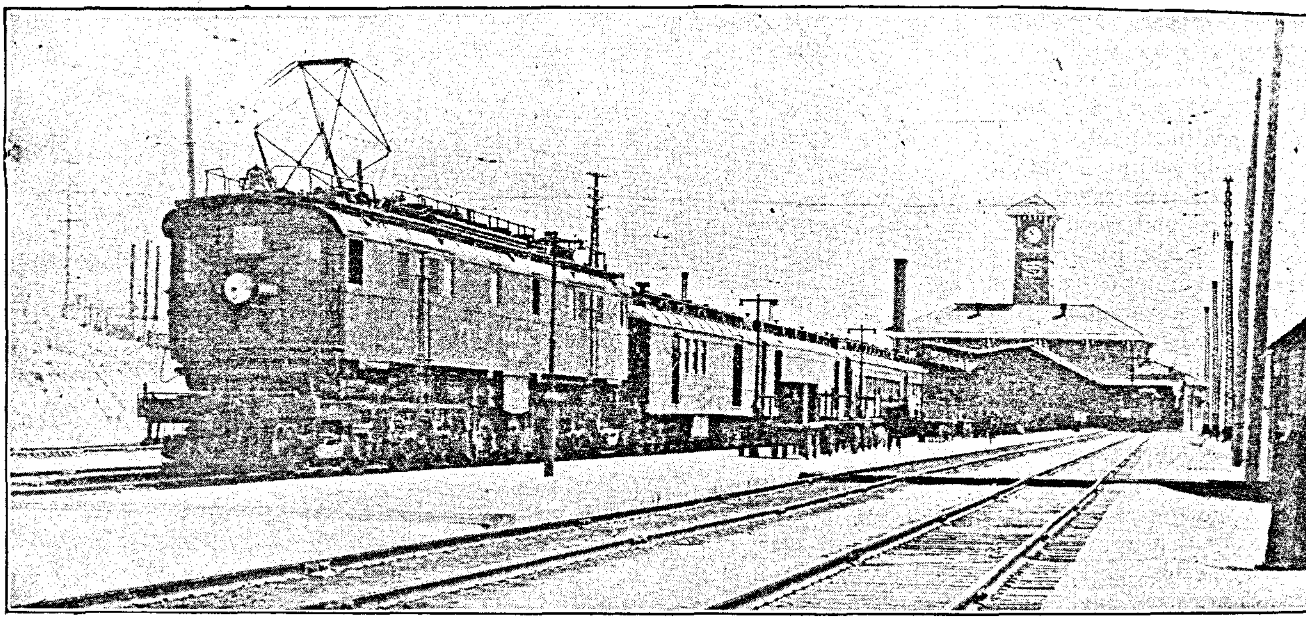


FIG. 4. ELECTRIC LOCOMOTIVE WITH PASSENGER TRAIN AT BUTTE, MONT.

being transmitted to the driving wheels by helical springs fitted between the arms of the quill and the spokes of the wheels. The motors, which have a continuous rating of about 540 hp., are mounted on the frame of the locomotive.

In these Westinghouse engines, therefore, the six driving axles have six motors with twelve armatures, while in the other design each of twelve axles has a single motor. The main dimensions of the two types of passenger engines are given in Table I. Each engine has an oil-fired boiler with capacity of 4,000 lb. of steam per hour for heating the engine and train, and air-

TABLE I. ELECTRIC PASSENGER LOCOMOTIVES; C., M. & ST. P. RY

	Westinghouse	General Electric
Wheel plan	4-6-2-2-6-4	2-4-8-8-4-2
Driving wheels, diameter	68 in	44 in.
Truck wheels, diameter	36 in.	36 in.
Weight on drivers, in working order	345,000 lb.	492,000 lb.
Weight, total, in working order	562,000 lb.	551,000 lb.
Non-spring borne weight per driving axle	7,800 lb.	9,500 lb.
Total wheelbase	79 ft. 10 in.	67 ft. 0 in.
Maximum rigid wheelbase	16 ft. 9 in.	13 ft. 11 in.
Number of driving axles	6	12
Number of motors	12	12
Total tractive effort; 1-hr. motor rating	66,000	46,000
Total hp., one-hour motor rating (contract)	4,000	3,240
Total hp. continuous (contract)	3,200	3,025

compressor capacity of 150 cu.ft. per minute for the brakes, pantagraphs and other equipment.

Operating Results—In most respects the general results of electrification have exceeded expectations and in no case have they fallen below the expectations, according to R. Beeuwkes, electrical engineer of the railroad. He states that even allowing for the increased investment charges the items of operating expense depending directly upon motive power are so reduced and the additional benefits indirectly obtained are so great as to justify consideration of extending the electrification even on sections with easier grades.

A summary of cost of electrification on the older line in 1914-16 has been given recently by Mr. Beeuwkes, this cost being considered more representative than that on the new line, where the work was done under conditions of delay and difficulty due to war conditions in 1917-18. The figures in Table II cover the work for 440 route miles, 364 miles of transmission line (exclusive of lines built by the power companies), 14 substations with a total capacity of 59,500 kw., 12 passenger locomotives, 30 freight locomotives and two switching locomotives. The figures in the table are intended mainly to show the relative importance of different items; they could not be applied in estimating the cost of similar work without a knowledge of the unit prices.

TABLE II. CONSTRUCTION COST FOR 440 MILES OF ELECTRIFICATION, 1914-1916; C., M. & ST. P. RY.

	Average Cost Per Route Mile	Average Unit Costs	Per Cent of Total Costs, Exclusive of Locomotives
Trolley system complete	$8,390	......	47.7
Transmission system, complete	2,360	......	13.3
Transmission line, per mile	......	$2,835	....
Substations, complete	6,050	......	34.4
Substations, each	......	189,400	...
Substation buildings	......	38,400	...
Substation apparatus	......	144,900	...
Operators' dwellings	......	6,100	...
Miscellaneous: Right of way, change to electric lines, storehouses, minor apparatus at shops and roundhouses	265	......	1.7
Engineering and administration, except for substations	514	......	2.9
Road locomotives, delivered	......	122,500	...
Switching locomotives, delivered	......	37,700	...
Total per route mile (exclusive of locomotives)	17,579	......	100.0

In Table III are shown comparative operating costs of freight traffic on the two older electrified divisions and the two steam-operated divisions adjoining them during the second half of 1918. For the purpose of comparison the figures for the Missoula electric division are taken as unity. Besides the more important reasons for the advantageous results of electrical operation, Mr. Beeuwkes considers that further improvement in operating cost is to be expected under normal conditions of operation. The marked decrease in cost of engine repairs is due to the fact that the cost of repairs per engine mile is much less for the electric locomotives than for the average steam locomotive replaced, and that the number of engine miles per 1,000 ton miles is also less on account of the greater capacity of the electric locomotive. On the Missoula division the total of engine miles per 1,000-ton miles was only about

55 per cent of that for the corresponding period in 1915 under steam operation.

TABLE III. COMPARATIVE OPERATING COSTS OF FREIGHT TRAFFIC (PER 1,000-TON-MILES); C., M. & ST. P. RY.: JULY-DEC. 1918

Division	Idaho	Missoula	Rocky Mountain	Musselshell
Motive power	Steam	Electric	Electric	Steam
Locomotive repairs	2.34	1	0.86	2.26
Train crews	3.05	1	1.46	1.61
Engine crews	2.17	1	1.30	1.21
Fuel or power[1]	2.34	1	1.04	1.38
Enginehouse	2.50	1	0.80	3.71
Yard service[2]	1.12	1	0.99	0.71
Total of items affected by motive power[3]	1.90	1	1.11	1.33

Note: Cost on Missoula Division taken as unity.
1. The item of "Fuel" is based on the average price for the system.
2. Considerable part of the switching was done by steam, as a sufficient number of electric switching engines had not been received.
3. In addition to the items tabulated this covers superintendence and maintenance of substations, transmission and trolley systems, water and fuel stations, shops and enginehouses; also locomotive and train supplies.

Reduction in expense for train crews is due to increased tons per train-mile and increased train speed. The expenses on the Missoula division were about 10 per cent less in 1918 than in 1915, but on the Idaho steam division they had more than doubled, according to Mr. Beeuwkes. For the expense of engine crews the same conditions obtain; with only a slight increase from 1915 to 1918 for the Missoula electric division but an increase of about 100 per cent for the Idaho steam division.

The relative reliability of electric and steam operation is considered an important point. Records for the six months from Oct. 1, 1919, to March 31, 1920, show that the 440 miles of electrically-operated territory had less delay than four steam divisions aggregating 945 miles, except for the steam divisions from Avery to Cle Elum, which are particularly favorable as to climatic, topographical and other conditions tending to cause delay. A summary of these results in three districts is shown in Table IV.

TABLE IV. RELIABILITY OF STEAM AND ELECTRIC FREIGHT TRAIN SERVICE

(Time in minutes per mile of line operated for six months).

	Marmouth to Harlowton	Harlowton to Avery	Avery to Cle Elum	Average for Four Steam Divisions
Miles	340	440	325	945
Motive power	Steam	Electric	Steam	Steam
Train delays affected by motive power (A)	62.95	52.73	35.34	74.75
Train delays not affected by motive power (B)	37.85	46.30	33.86	46.77
Total	100.80	99.03	69.20	121.52
Accidents and derailments (Included in A)	2.25	0.15	3.85	.....
Time lost	69.7	8.94	0.00	.....
Time made up	35.6	100.0	81.00	.....

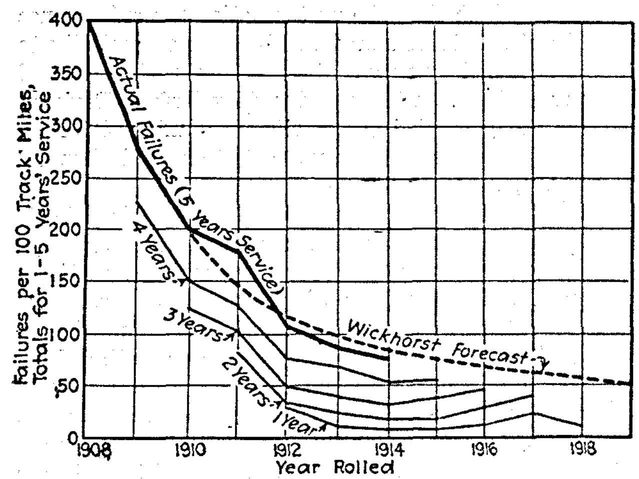
A. Delays due to other trains, signals, slow orders, excess time in switching, extra cars on train, bad weather, poor coal, trolley and substation defects, engine conditions, and accidents and derailments due to engines.
B. Delays due to waiting for connecting trains, handling heavy mail and express, extra stops, car conditions, slides, snow and accidents not due to engines.

Records for the year 1919 show that with a freight traffic of 2,476,085,000 gross ton miles behind the engines, the cost per kw.-hr. per 1,000 ton miles was 22.3c. For 378,080,000 passenger ton miles, the cost was 38.1c. per kw.-hr. per 1,000 ton-miles. The cost of power, including operating and maintenance expenses of substations and transmission lines, was 1.1c. per kw.-hr. as delivered at the locomotive.

This electrification work is under the direct charge of R. Beeuwkes, electrical engineer, Chicago, Milwaukee & St. Paul Ry.

Decrease in Rail Failures Confirmed by Latest Statistics

PUBLICATION of the 1919 rail failure statistics prepared by M. H. Wickhorst, engineer to the Rail Committee of the American Railway Engineering Association, in a bulletin just issued by the association, confirms with astonishing accuracy forecasts made four or five years ago concerning the probable future improvement in rail service. In the diagram herewith is reproduced from the bulletin the curve of rail failures during the sixth year of service (marked five years' service), and for comparison with it the forecast made by Mr. Wickhorst several years ago (shown by dash lines). In addition the curves of failures after four years, three years, two years and one year of service have been plotted from the tables in the report. The abscissa in every case represents the year during which the rails in question were rolled. The several curves are quite consistent. All of them show a hump at the year 1912, and a further abnormal rise for the years 1916 and 1917.



RAIL FAILURES FOR PRINCIPAL CARRIERS

The data of the tables cover about 85 railroads, including all the large systems of the United States and Canada and a considerable number of the shorter lines. Ten rolling mills are represented as producers of the rails. Both bessemer and openhearth rail are included, but the former is increasingly unimportant in the later rollings. Only rail lots of 1,000 tons or more were used in the tabulations, as it was concluded that a lot of less than 1,000 tons furnished by a given mill to a given railroad in one year would not affect the group totals and averages. Reduction of the data to 100 miles of track covered by the particular rolling brings the resulting figures to a uniform basis.

In the report are included detail tables and diagrams showing the performance of each lot (of 1,000 tons or over) of rail furnished by each mill to each railroad in a particular year, and summing the results for railroads and for mills in various ways. Irregular variations occur in all these summaries, however, none of them apparently tending to point in the direction of the main responsibility for rail weakness. The only consistent feature of the records is the continuous improvement shown by the diagram here reproduced. It means that the rate of failure of rails, amounting to nearly 400 per year per 100 track-miles for 1,908 rails after five years of service, has been decreased by more than 80 per cent in seven years.